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THE EFFECT OF MILK[1] ON THE BROMATE REQUIREMENTS OF FLOURS[2]

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Although the use of milk in domestic bread making doubtlessly dates from antiquity, its application in commercial baking is of comparatively recent origin. It is difficult to say what purposes first led to its use but it is reasonable to assume that the increase in nutritive property of the bread was an important consideration. Certainly that has been given as an important reason for its use, and various investigations have been conducted to prove that milk improves the nutritional value of bread made with it as one of the components of the formula. Sherman *et al.* (1921), Morison and Amidon (1923), and Fairbanks (1938) have demonstrated that inclusion of milk in the baking formula materially improved the value of bread as a single diet. This is a conclusion that could be reached by *a priori* reasoning if it were assumed that the digestibility of the milk components was not impaired during the processes of fermentation and baking.

Early in the use of milk in commercial bread making it was observed that different preparations varied in their effects on the bread. A number of investigations were conducted to determine the causes of these variations and to discover the conditions necessary for producing milk preparations of uniform, satisfactory baking quality, and good nutritive value. Greenbank *et al.* (1927) and Grewe and Holm (1928) found that the preheating of skim milk before drying was an important factor influencing the quality of the dried product. The latter authors concluded that temperatures between 73°C. and 93°C. gave satisfactory results. They also observed that the preheating increased the viscosity of the water suspension of the powdered milk.

[1] The term milk is used to indicate dry-milk solids, the product obtained by removal of water from skim milk.

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Johnson and Ward (1936) showed that although the viscosity of non-sweetened milk was increased by preheating and could also be increased by other methods, viscosity is not necessarily a good indication of the baking quality of the preparations. Fairbanks and Mitchell (1935) observed that the proteins of milk powder made from skim milk that had been preheated at temperatures high enough to produce scorching were reduced in biological value by as much as 20%, and were deficient in lysine. As normal milk and unscorched dry-milk solids are not deficient in this amino acid, it seemed evident that it is susceptible to damage by too high temperatures during the preheating process.

Skovholt and Bailey (1932b) found that the baking quality of a series of dried milks could be ranked fairly well by the plasticity curves obtained on a farinograph and with salt as an ingredient of the doughs. The amount of decrease in dough plasticity with extended mixing was found to give a significant correlation with baking quality of various dried-milk preparations.

The effect of dry-milk solids on the physical properties of doughs has been studied in attempts to obtain a better understanding of the manner in which this material functions. St. John and Bailey (1929b) found that extensibility of the dough was not materially affected by the inclusion of 10% or less of dry-milk solids. Skovholt and Bailey (1932b) observed that inclusion of dry-milk solids in wheat flour doughs increased the time required to reach the maximum plasticity as indicated by the farinograph. This was corroborated by Bohn and Bailey (1937), who pointed out also that the stress readings of a dough after mixing are markedly decreased by the inclusion of dry-milk-solids-not-fat.

A number of other investigations have revealed some interesting results accruing from the inclusion of dry-milk solids in the baking formula. Amidon (1926) found a general optimum of baking qualities at a dry-milk-solids level of approximately 7%. Grewe (1928) reported that the volume, grain, break, shred, and color were improved by the addition of dry-milk solids to doughs. She also reported that the tendency for the break to "run wild" was reduced and that the range of fermentation time over which good bread could be obtained was increased by the addition of dry-milk solids. St. John and Bailey (1929a) showed that total production of CO_2 in yeast-leavened doughs was increased when dry-milk solids was superimposed on the control formula. The rate of increase in volume and total displacement of doughs was practically the same with or without milk in the formula. The buffer action of dry-milk solids was appreciable as shown by the initial hydrogen-ion concentration of the freshly mixed doughs and

the relative rate of change in pH of the control and milk-containing doughs. Skovholt and Bailey (1931, 1937) found that dry-milk solids suppresses the saccharogenic activity of flour-water suspensions and that reduction in diastatic activity is the result of reduced hydrogen-ion concentration effected by the dry-milk solids. They stated that gas production from fermenting doughs was accelerated by dry-milk solids if sufficient sugar was available.

Working (1928) observed that when dry-milk solids were used in no-time doughs an improvement was obtained with addition of both a phosphatide and an oxidizing agent. Skovholt and Bailey (1932a) presented data which indicated that either malt or Arkady used in conjunction with dry-milk solids gave complementary effects.

In this brief review it can be observed that much of the earlier work has been directed toward learning how to prepare milk suited to bread making, ascertaining the best dosages to use, and attempting to measure the effects of milk on the physical properties of doughs. As a result of these investigations, satisfactory milk preparations are now available to the commercial bakers and increasing quantities are being used by the industry. Other improving agents are also being used in large quantities, particularly with the hard red winter wheat flours. Most important of these are the chlorine-type bleaching agents and certain "flour improvers," the majority of which contain potassium bromate as the active "oxidizing" component. As milk and bromate may each improve flours, it is a matter of importance to know whether their actions are supplementary, complementary, or independent. The work reported in this paper was directed toward the problem of the effect of dry-milk solids on the bromate requirements of various types of flours, with particular emphasis on the hard red winter class.

Materials and Methods

The flours used in this investigation are described in Table I. They were chosen as representative of the various types used in commercial bread production in different parts of the country, as well as flours which are used for the production of cake, pastries, and alimentary pastes. They consisted of commercially milled and experimentally milled flours, both bleached and unbleached. Two of the flours (Nos. 10 and 11, an unbleached Tenmarq and an unbleached Chiefkan) were extracted with ethyl ether for further investigation. This extraction was performed in an enlarged extractor of the Soxhlet type for a period of at least 24 hours. After extraction the flours were exposed to the atmosphere for a time sufficient to remove all traces of ether.

Dry-milk solids is the product resulting from the removal of water from liquid skim milk and contains less than 5% moisture and less

TABLE I

FLOURS USED, THEIR PROTEIN CONTENTS, BLEACHING TREATMENTS, AND THE METHODS BY WHICH THEY WERE MILLED

Sample No.	Wheat variety or class from which flour was milled	Protein, 13.5% moisture basis	Bleaching treatment	Method of milling
		%		
1	Low-protein composite from Turkey, Tenmarq, and Blackhull	9.9	Unbleached	Experimental
2	High-protein composite from Turkey, Tenmarq, and Blackhull	14.4	Unbleached	Experimental
3	Hard red winter (Kan.)	11.5	Bleached	Commercial
4	Hard red spring (Minn.)	14.7	Unbleached	Commercial
5	Hard red spring (Can.)	13.3	Unbleached	Commercial
6	Soft red winter (Mo.)	9.3	Bleached	Commercial
7	Soft red winter (Mo.)	10.3	Unbleached	Commercial
8	Pacific short patent (Oreg.)	6.8	Bleached	Commercial
9	Durum (N. D.)	11.1	Unbleached	Experimental
10	Tenmarq (Kan.)	9.8	Unbleached	Commercial scale, experimental mill
11	Chiefkan (Kan.)	11.5	Unbleached	Commercial scale, experimental mill

than 1½% fat. The dry-milk solids used in this investigation was manufactured by the spray process. A sample of this milk was compared with a sample of known baking quality and gave comparable results in a baking test. The dry-milk solids was incorporated in the dough by mixing the dry ingredients thoroughly with the flour before the addition of any of the other baking ingredients.

The baking procedure used was a modification of the standard method approved by the American Association of Cereal Chemists. The formula involved the use of the ingredients listed below and the quantities indicated. Percentages of ingredients are based on flour as 100 per cent. Formula: Flour 100%; water as required; yeast 2%; sugar 6%; salt 1.75%; shortening 3%; bromate and dry-milk solids in variable quantities. Baking absorption was determined by a method developed by Finney.[4] This was increased 1% for each 1% of dry-milk solids except where 8% of dry-milk solids was used, in which case the absorption increase was the same as that for the 6% dry-milk-solids doughs. This procedure was followed because previous experience indicated that the doughs became too sticky to handle properly if this increase was exceeded. Doughs were mixed until they attained an optimum consistency as determined by visual observation. Finney

[4] Paper read at the tri-section meeting of the American Association of Cereal Chemists, Manhattan, Kansas, 1939.

and Barmore[5] have shown that this procedure is preferable to mixing for a definite period of time for all samples. The doughs were mixed from 200 g. of flour, divided into two equal parts, fermented, and proofed at 86°F. The doughs were fermented and proofed according to the time schedule from the standard method of the American Association of Cereal Chemists. Punching was done with a National pup sheeting roll and molding of the loaves by a Thompson laboratory scale molder. The loaves were baked in tall narrow pans at 232°C. in a Despatch oven with rotating hearth. Loaf volume was measured immediately upon removal of the loaves from the oven. A National pup-loaf measuring device was used to determine the volume. The figures for loaf volume given in the tables are averages of two loaves measured in this manner. The loaves were cut the day following baking for scoring of the interior characteristics and for obtaining a photographic record of the interior grain structure.

Discussion of the Data

Preliminary investigations showed that the amount of potassium bromate necessary to produce optimum loaves of good texture was greater when milk was included in the formula than when it was absent. The amount of bromate varied with the protein content of the flours, those of high protein requiring more than those of low protein content.

In order to investigate this further, two winter-wheat-flour composites were prepared from the supplies of experimentally milled flour available. The composites were made from approximately equal amounts of Turkey, Tenmarq, and Blackhull, using samples of the protein-variety series described by Larmour, Working, and Ofelt (1939). The lower-protein sample had 9.9% protein and the higher, 14.4%. While these samples do not represent the extremes of the range in protein content in the 1938 crop, they provided fairly representative samples of about the lowest and highest protein that might be expected to occur in commercial bread flours. They were baked in two series, with and without dry-milk solids (6%), each series having varying amounts of potassium bromate in the formulas. The baking data are given in Table II (samples 1 and 2) and are shown graphically in Figure 1.

The low-protein flour without milk showed a distinct maximum with 0.001% bromate. With greater amounts of bromate the loaf volume decreased and texture became poorer. When milk was used the optimum occurred with 0.002% bromate, and with increasing amounts up to 0.004% there was no diminution in volume or texture

[5] Paper read at Annual Meeting of American Association of Cereal Chemists at Kansas City, 1939.

TABLE II

BAKING DATA SHOWING THE INTERRELATIONSHIP BETWEEN DRY-MILK SOLIDS (DMS) AND $KBrO_3$ WITH VARIOUS FLOURS

Sample No.	Treatment	Dosage of $KBrO_3$ (Mg./100 g. flour)											
		0		1		2		3		4		5	
		Loaf vol.	Texture	Loaf vol.	Texture	Loaf vol.	Texture	Loaf vol.	Texture	Loaf vol.	Texture	Loaf vol.	Texture
1	Milk-free	610	68	655	68	625	63	603	50	600	55	555	40
	6% DMS	738	75	770	75	805	73	808	78	805	77	770	71
2	Milk-free	708	76	883	93	905	85	830	78	745	75	760	75
	6% DMS	755	69	865	88	913	90	925	89	998	89	1003	89
3	Milk-free	715	95	735	90	693	83	690	79	673	73	663	71
	6% DMS	770	96	835	98	825	98	860	89	822	93	803	93
4	Milk-free	768	85	888	90	770	70	695	63	690	60		
	6% DMS	817	93	960	95	993	80	978	80	895	75		
5	Milk-free	688	83	710	79	635	73	570	64	568	60	538	54
	6% DMS	823	93	888	92	888	92	845	84	813	68	733	65
6	Milk-free	600	68	565	55	550	55	533	50	530	50	515	45
	6% DMS	720	88	738	85	700	83	708	80	700	75	675	75
7	Milk-free	618	65	625	71	622	49	595	50	600	52	578	47
	6% DMS	768	79	790	77	690	83	818	78	780	78	762	70
8	Milk-free	490	50	455	45	463	43	460	43	440	40	438	40
	6% DMS	580	53	560	49	—	—	—	—	—	—	—	—
9	Milk-free	485	50	463	43	443	35	435	25	—	—	—	—
	6% DMS	513	60	513	48	513	45	493	33	—	—	—	—

score. There was thus a "plateau" between 0.002% and 0.004% bromate over which constant values for volume and texture were obtained.

The high-protein flour behaved somewhat differently. Without milk it gave an optimum at 0.002% bromate, although this was only slightly higher than at 0.001% bromate. The increase in volume due to bromate was great, and the decrease due to overdosage was also great. With the 6% milk, the volumes were the same as for "without milk" until the 0.002% dosage was reached. Thereafter the doughs with milk continued increasing in volume instead of decreasing as the checks did. There was no significant difference between the 0.004% and 0.005% dosages; evidently the maximum had been reached with 0.004% bromate.

With both low and high-protein flours the optimum dosage of bromate was twice as great in the milk doughs as in the check doughs. It should be noted too that at optimum dosage of bromate the low-

protein sample showed greater effects due to milk than did the high-protein sample, the increases over the best volumes obtained in the checks being 153 and 98 cc. respectively.

The most important observation in this experiment was that in the presence of 6% dry-milk solids it is possible to use one dosage of bro-

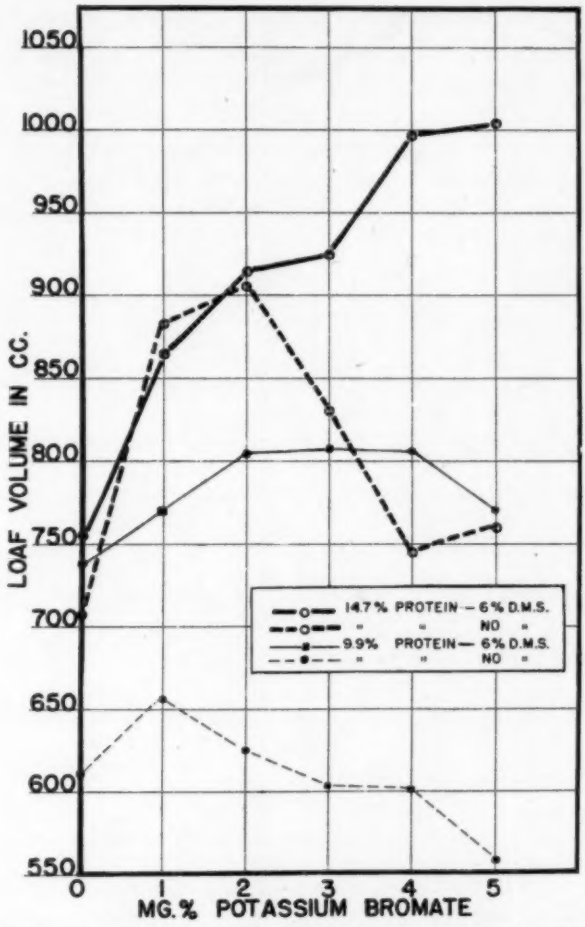

Fig. 1. Baking data showing the interrelationship between dry-milk solids and $KBrO_3$ on two flours, one from a low-protein composite wheat (No. 1, Table I) and the other from a high-protein composite wheat (No. 2, Table I).

mate that will give nearly optimum baking results with both low- and high-protein winter-wheat flours. In Figure 1 it can be seen that 0.004% bromate brought the high-protein flour to what may have been the beginning of its "plateau" and carried the low-protein flour to the end of its "plateau" or optimum range. This is a curious condition, which if applicable to flours in general would prove of great value in

both experimental and commercial baking. In experimental baking it would mean that a sufficiently high dosage of bromate could be used to ensure optimum development of the high-protein samples without

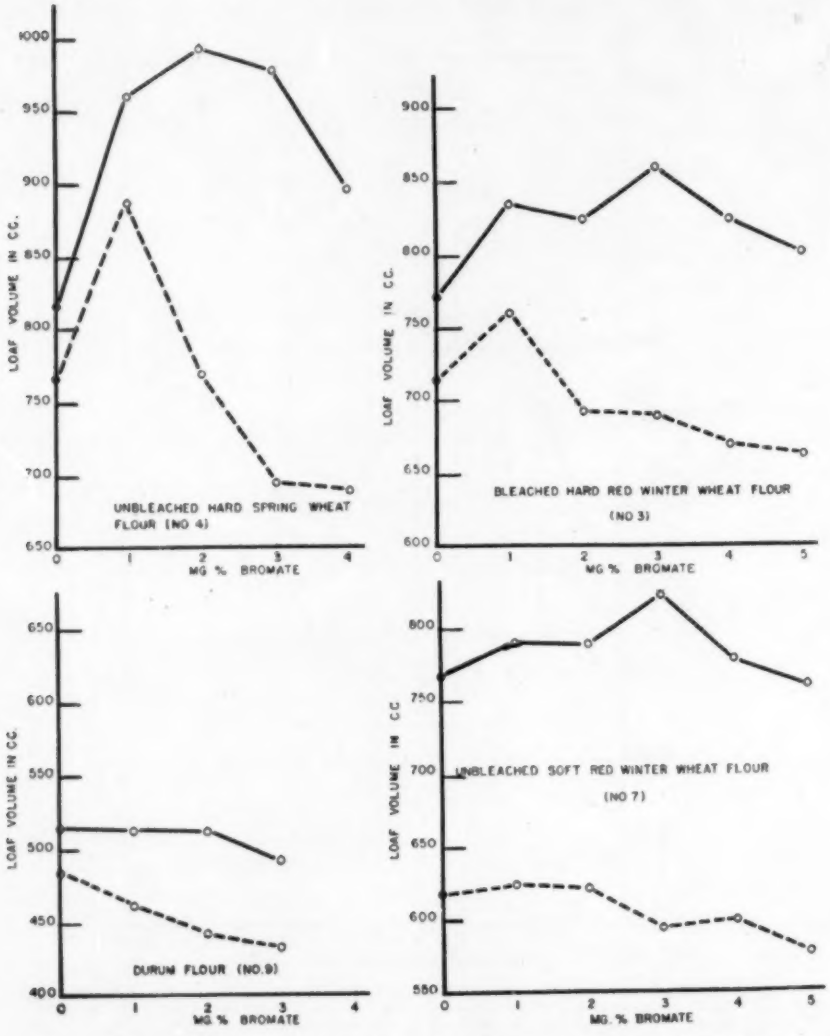

Fig. 2. Baking data showing the interrelationship between dry-milk solids and $KBrO_3$ on three commercial flours (No. 3, 4, and 7, Table I) and an experimentally milled durum flour (No. 9). Broken line represents milk-free doughs; solid line represents doughs made with 6% dry milk solids.

the risk of damaging those of lower bromate requirements. In commercial practice it would mean that there would be much less danger of "overoxidizing" flours that had been brought close to their optimum condition in the process of manufacture.

In order to learn whether or not these observations, obtained with experimentally milled hard winter wheat flours, were applicable to commercially-milled flours, and particularly to different classes of flour, a series composed of various types was tested in the manner described above. Description of these samples is given in Table I. The baking data are presented in Table II. (The data obtained with several of the more interesting flours are shown graphically in Figure 2.)

All these flours except the very low-protein Pacific short patent flour gave results somewhat comparable to those obtained with samples 1 and 2. It is true that not all of them would tolerate 0.004% bromate even with 6% milk present, but they showed the common characteristic of having a range of tolerance toward bromate in the presence of dry-milk solids much broader than in the plain doughs.

TABLE III

BAKING DATA SHOWING THE INTERRELATIONSHIP BETWEEN DRY-MILK SOLIDS (DMS) AND $KBrO_3$ ON NORMAL, UNBLEACHED CHIEFKAN AND TENMARQ FLOURS AND ON THE SAME FLOURS FOLLOWING EXTRACTION WITH ETHYL ETHER

Flour	Treatment	Dosages of $KBrO_3$ (Mg./100 g. flour)											
		0		1		2		3		4		5	
		Loaf vol.	Texture	Loaf vol.	Texture	Loaf vol.	Texture	Loaf vol.	Texture	Loaf vol.	Texture	Loaf vol.	Texture
Chiefkan (No. 11)	Milk-free	535	39	688	81	680	81	650	78	638	78	—	—
	6% DMS	572	20	717	75	750	100	792	100	730	95	710	80
Extracted Chiefkan	Milk-free	503	45	595	75	618	73	598	63	538	63	—	—
	6% DMS	555	59	658	75	695	75	680	75	680	73	—	—
Tenmarq (No. 10)	Milk-free	600	60	593	60	558	55	550	50	543	50	545	50
	6% DMS	730	65	750	70	752	75	720	80	690	80	680	75
Extracted Tenmarq	Milk-free	495	50	490	50	480	50	475	50	473	48	480	48
	6% DMS	615	70	605	68	605	70	550[1]	70	613	73	625	70

[1] This sample received improper treatment in the molding equipment.

Sample No. 3, Table II, a commercial, bleached hard winter wheat flour of 11.5% protein content, showed an abrupt optimum with 0.001% bromate without milk. With milk there was an optimum at 0.003% bromate and it seems likely that the range of bromate tolerance was 0.001% to 0.004%. Even with 0.005% bromate and 6% milk there was not a serious diminution of volume or texture. This sample showed characteristics similar to No. 1, the low-protein experimentally milled flour.

A commercial, unbleached hard red spring wheat flour milled in Minnesota, of 14.7% protein (Sample No. 4, Table II), gave a very

sharp maximum value for loaf volume with the milk-free formulas, characterized by a sharp rise at 0.001% bromate dosage, followed by a decrease equal to the rise at 0.002% dosage. Further decrease occurred with increasing amounts of bromate. When the milk was included in the formula the optimum range was at least 0.002% to 0.003% bromate (probably 0.001% to 0.003%). It is generally recognized that the hard spring wheat flours require somewhat less "oxidation" than the hard winter flours, and the shorter range of bromate tolerance noted in this flour is doubtlessly a reflection of this characteristic.

Sample No. 5 was a commercial, unbleached flour obtained from a large Canadian mill. It was said to be a first clear flour, and as such could not be regarded as typical of Canadian spring wheat flours. It proved to be a very interesting sample, however, and the data have been included here because they represent an example of low positive response to bromate (either with or without milk), high susceptibility to overbromating, and a very marked positive response to the presence of dry-milk solids in the baking formula. The milk increased the bromate tolerance to 2 mg., but this was the lowest range observed except in the case of sample No. 10, which will be discussed later.

Several samples of soft winter wheat flour were also studied. First to be tested was a commercial bleached soft red winter wheat flour milled in Eastern Missouri and said to be typical of the flour produced from that class of wheat. Later another sample, unbleached, was obtained from the same mill. The two samples were of 9.3% and 10.3% protein respectively. It is evident that sample No. 6 had been treated to the limit in milling, because it did not show any tolerance for bromate in the absence of milk; the best volume and texture were obtained with the unbromated dough. With milk there was a slight but scarcely significant increase in volume with 0.001% bromate. This was accompanied by a decrease in texture score. However, there was no great decrease in volume in this series until a dosage of 0.005% bromate had been reached.

The unbleached soft red winter wheat sample, No. 7, gave very little positive response to bromate either with or without milk. Without milk there was no effect on volume from 0.001% and 0.002% bromate, but in the latter case the texture fell off 22 points. Higher dosages gave somewhat lower volumes but no further reduction in texture score. With milk there was a small increase in volume due to bromate but the whole range of volume change was only 56 cc. Neither was there a great deal of variation in texture in the series. It is worth noting, however, that with 0.002% bromate the texture of the samples treated with milk was high, while that of the milk-free sample

had dropped to the low value of 49, which indicates very poor texture indeed. Thus while there is not much evidence of effect of milk on the volumes, it does appear to maintain the texture.

The Pacific short patent flour, sample No. 8, was very low in protein and was a typical cake flour. It was included in this series merely as a matter of interest. It was not possible to handle the doughs made with 6% milk and bromate in excess of 0.001%. The data obtained indicate that this flour would not tolerate bromate in even 0.001% dosage. But in the plain doughs there was little decrease in volume. The flour was not sensitive and was too weak to be regarded as a bread flour.

Sample No. 9 was experimentally milled from durum wheat obtained from North Dakota. It was reputed to be a "typical" sample, although the protein content was too low to be representative of the crop. The response to bromate was negative, though not great, in the plain doughs. Milk reduced the negative volume response almost to zero and improved the texture considerably.

The soft-wheat and durum-wheat flours used in this study showed very little volume response to the action of bromate either with or without milk. There was a notable effect of milk in these samples on the textures of the bread. With the plain formulas bromate damaged the texture when used in the higher dosages but did not materially diminish the volume; milk reduced this damaging effect greatly.

Among the hard winter wheats there are many varieties which show quite a large range of characteristics. The varieties Tenmarq and Chiefkan probably represent the extremes. Tenmarq is said to possess some of the characteristics of its Marquis parent. It probably requires less bleaching than most winter-wheat varieties; it has a relatively long mixing time; it exhibits the long wheat-meal-fermentation time of the spring wheats; and there is considerable evidence that it needs less bromate than the average hard winter wheat. Chiefkan, on the other hand, has very short mixing time, usually gives short wheat-meal-fermentation time, and requires heavy dosages of bromate. The differences in their baking behavior can be seen in the data in Table III and in the graphs in Figure 3.

With milk-free doughs Tenmarq gave evidence of not requiring any bromate, while Chiefkan showed a great increase in both volume and texture with 0.001% bromate. With 6% milk Tenmarq gave a slight increase in volume and considerable improvement in texture on addition of bromate up to 0.002%; greater amounts of bromate decreased the volume but not the texture. The Chiefkan sample showed progressive increase in volume and a most astonishing improvement in texture with bromate up to 0.003%.

Perhaps the most outstanding difference of the Chiefkan doughs was in connection with their "feel," a property real enough to the baker but one almost impossible to describe clearly. These doughs lacked "resiliency," they "tended to flatten out on standing;" they were "soft and rather inelastic." These properties were particularly

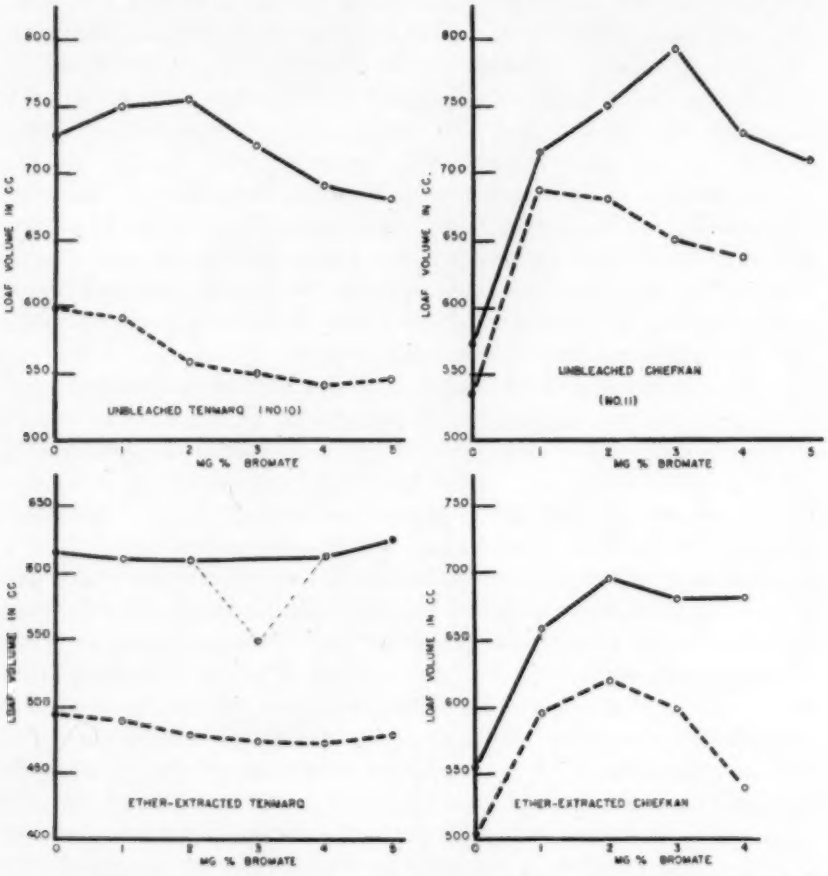

Fig. 3. Baking data showing the inter-relationship between dry-milk solids and $KBrO_3$ on Tenmarq (No. 10, Table I) and Chiefkan (No. 11) flours and also on the same flours following extraction with ethyl ether. Broken line represents milk-free doughs; solid line represents doughs made with 6% dry milk solids.

noticeable in the unbromated doughs but they persisted to some extent in the bromated doughs also. With both milk and bromate the doughs were similar to standard hard winter flour doughs. Some of these peculiar dough characteristics were like those of dough made from flour that had deteriorated through overaging.

Kozmin (1935) and Barton-Wright (1938) have shown that unsaturated fatty acids may be responsible for profound changes in the

colloidal nature of doughs and have suggested that they may be the cause of the damage occurring in overaging. Removal of these fatty acids by ether extraction restores, in part or in whole, the original properties of the flour. Having in mind the possibility that the differences between Chiefkan and Tenmarq flours might be due to the presence of free fatty acids or other similarly acting substances in varying amounts, 2500-g. samples of each flour were extracted with ether in a large size continuous extractor constructed by E. B. Working, and subsequently baked with various amounts of bromate. The data are given in Table III and curves showing the relation of loaf volume to bromate dosage in Figure 3.

There was no evidence of decreased differentiation of these flours as a result of ether extraction. The Chiefkan flour still responded notably to bromate, while the Tenmarq flour gave practically no response. The loaf volume level was lowered approximately 50 cc. for Chiefkan and 100 cc. for Tenmarq. The loaf volume and texture response to milk were very little changed at all bromate levels. It thus seems evident that the differences in dough characteristics of these two flours were not attributable to differences in naturally occurring amounts of any ether-soluble substance.

There was next investigated the possibility that these two flours differed in the amount or activity of protease. If the theory advanced by Jørgenson (1935, 1935a, 1936, 1939) and supported by Balls and Hale (1936, 1938) and Flohil (1936), that bromate owes its effect to inhibition of protease activity in flour, were correct, the differences in bromate response of these two flours might very well be accounted for on this basis. The Chiefkan ought to have the higher protease content, or activity, because it produced exceedingly poor bread, without bromate, and showed a remarkable improvement upon its addition, whereas the Tenmarq produced good bread without bromate and only slightly better when it was added. It has been shown above that the differences in bread characteristics were reduced greatly by the use of the optimum amount of bromate for each flour, namely 0.003% for Chiefkan and 0.002% for Tenmarq. If this were due to different protease contents or activities, a contrary effect should be obtained by addition of protease activators; their differences ought to be accentuated.

With these considerations in mind, the two flours were baked with two dosages of cysteine monohydrochloride, 1 mg. and 5 mg. per 100 g. of flour. The data in Table IV show that with milk-free doughs there was no change in loaf volume due to cysteine in either flour. With 6% milk there was a small decrease in volume, which may have been

TABLE IV

BAKING DATA ON UNBLEACHED TENMARQ AND CHIEFKAN FLOURS SHOWING THE COMPARATIVE EFFECTS OF VARYING CONCENTRATIONS OF CYSTEINE MONOHYDROCHLORIDE ON MILK-FREE DOUGHS AND DOUGHS CONTAINING 6% DRY-MILK SOLIDS (DMS)

Flour	Treatment per 100 g. flour	Milk-free doughs		6% DMS	
		Volume	Score of crumb	Volume	Score of crumb
		cc.		*cc.*	
Tenmarq	Control (No bromate)	600	60	730	65
	1 mg. cysteine monohydrochloride	608	78	695	85
	5 mg. cysteine monohydrochloride	598	78	678	88
Chiefkan	Control (No bromate)	535	39	572	20
	1 mg. cysteine monohydrochloride	535	46	538	33
	5 mg. cysteine monohydrochloride	538	46	543	33

attributable to secular variability, as the checks were not baked at the same time as the samples with cysteine. There was no significant difference between loaves having 1 and 5 mg. of the cysteine. In all cases the texture scores of bread made with cysteine in the formula were better than those of the checks. In the baking results, the only effect that could be attributed to cysteine was an improvement in texture. There was certainly no differential effect on the two flours.

An important observation made in the course of this experiment was that cysteine caused a very definite decrease in mixing time of all doughs in which it was included. This effect was somewhat greater with the higher dosage. Chiefkan, naturally a short mixing flour, became almost too sticky to handle after mixing one minute in the Swanson-Working mixer. Tenmarq, which normally required 5 minutes of mixing, was reduced to about 2.5 minutes. The effect of cysteine seems to occur almost instantaneously. This was also shown in the recording dough-mixer curves by a very sharp rise to the maximum and a rapid drop and diminution of width of the curve. The speed with which cysteine affects the dough appeared to be much too rapid to be attributed to enzyme action. It had the characteristics of a colloidal effect.

The results of this experiment provide no evidence of increased differentiation attributable to a protease activator. One can conclude that protease content or activity was not the factor responsible for the great differences in bromate response of these two flours.

Specific Effects of Milk

The response of these different flours to milk is difficult to assess properly because the bromate requirements are different for milk-free doughs and those containing milk. Direct comparisons at any one level of bromate dosage are bound to be misleading. Perhaps the most admissible comparisons would be on the non-bromated doughs, but even in that case the natural differences in bromate requirement of the flours would tend to give incorrect information. With certain flours such as the soft red winters which have little response to bromate, the approximate effect of milk might be estimated at almost any level of bromate without very great error. This would not be true of flours such as the hard red springs or hard winters because the milk-free doughs may be actually overbromated, resulting in decreased volume and texture, while those with milk are still short of their optimum condition.

The changes in loaf volume attributable to the presence of 6% dry-milk solids, at all bromate levels studied, are given in Table V.

TABLE V

IMPROVEMENT IN LOAF VOLUME RESULTING FROM THE INCLUSION OF 6% DRY-MILK SOLIDS IN THE FORMULA

Sample No.	Differences in loaf volumes between milk-free doughs and doughs containing 6% dry-milk solids at various dosages of bromate (Mg./100 g. flour)						Diff. in vol.—optimum milk doughs and milk-free doughs
	0	1	2	3	4	5	
1	128	115	180	205	205	215	153
2	47	18	8	95	253	243	98
3	55	100	132	170	149	140	125
4	49	72	223	273	205	—	105
5	153	178	253	265	245	195	178
6	120	173	150	175	170	160	138
7	150	165	168	213	180	184	193
9	28	50	70	58	—	28	28
10	130	157	194	170	147	152	152
11	37	29	70	142	98	104	104

In the last column of the table the differences between the best loaves of the check series and the best loaves of the series containing 6% dry-milk solids are given. For example with the commercial hard red spring flour No. 4, the value 105 cc. was obtained by subtracting the loaf volume 887 cc., obtained with 0.001% bromate, from the loaf-volume figure 992 cc., obtained with 0.003% bromate and 6% dry-milk solids. These values represent the extent to which 6% dry-milk solids improves the loaf volume beyond the optimum obtainable with bromate alone.

Flours that have slight response to bromate tend in general to exhibit the greater response to milk. With Nos. 1 and 2, which possessed the same inherent quality but were different in protein content, the low-protein sample No. 1 gave small response to bromate and relatively large response to milk (based on the milk-free, non-bromated check samples, column 0). The high-protein sample No. 2 showed the converse effect, large response to bromate and small response to milk. Comparisons of Nos. 10 and 11, and Nos. 4 and 7, show similar results.

When one compares these values with those given in the last column of Table V, it is seen that they agree in a general way. One might predict the nature of the differences to be found in "net response" to milk in these three pairs of flours, but the relative responses obtained from the non-bromated doughs would be badly out of line with the "net responses."

In the foregoing comparisons the greater effect of milk occurred with the low-protein samples, and one might be inclined to associate low protein, low bromate response, and large "net milk" response. The hard red spring unbleached clear flour, No. 5, provides an exception because it was relatively high in protein content, low in bromate response, and high in "net response" to milk. That would, however, still leave the possibility of an association between low-bromate and high-milk responses were it not for the durum sample, No. 9, which had small response to both bromate and milk. Despite these exceptions, it seems probable that there may be an inverse relationship between bromate and milk responses in patent or straight bread flours.

Summary

A series of flours, including hard red spring, hard red winter, soft red winter, white, and durum wheat flours was studied in respect to the effects of potassium bromate and of dry-milk solids in the baking formulas. In general the inclusion of 6% dry-milk solids creates a tolerance toward bromate which tends to prevent damage to loaf volume and to grain and texture when large dosages of this reagent are used. Even when the effect is small for loaf volume it remains marked for grain and texture. This buffering effect toward bromate has important commercial significance because it provides a safeguard against the possibility of damaging flours that have already been brought close to their optimum "oxidation" condition by bleaching or by the addition of other oxidizing agents.

Examination of two of the flours which had been thoroughly extracted with ether indicated that this buffering effect was not associated with the ether-soluble components of the flours.

Treatment of two flours that responded quite differently to both bromate and milk, with cysteine-hydrochloride, a protease activator, resulted in no increased differentiation of the flours. This was interpreted to mean that the protease content of the flours was not responsible for the differences noted.

Dry-milk solids, together with the appropriate amounts of potassium bromate, produced increases in loaf volumes and improvements in texture beyond what could be obtained with optimum amounts of bromate alone. The extent of this response appeared to be inversely related to bromate response in most cases. Exceptions were noted in the cases of the durum and the unbleached hard red spring clear flours.

In certain flours greater improvements were obtained with milk alone than with the optimum dosage of bromate. This was particularly applicable to the low-strength flours. In all cases, however, milk gave some improvement in both loaf volume and texture over what could be obtained with bromate alone.

The variations in magnitude of response to milk are important commercially and deserve much more investigation.

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QUALITY TESTS ON SOFT RED WINTER WHEATS OF KANSAS[1]

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Soft red winter wheats represent a large percentage of the total wheat production of the United States, and in Europe they are the predominant type. They were used for making bread flours many centuries before the hard types, as we know them today, were introduced. Only within comparatively recent times have the hard wheats come to be regarded by many bakers as *necessary* in the manufacture of bread flours. Even today a large proportion of the bread flour of the world is made almost entirely from soft wheats.

[1] Contribution No. 63 from the Department of Milling Industry.

When the great central plains area of North America was opened up to farming, it was discovered that the climate and soil of the western part of the region were particularly well suited to the growing of wheat of a hard, vitreous character. As this type of wheat became available in commercial quantities, it was found that when mixed with the softer types the bread-making properties of the blends were superior and gradually new standards of quality in flour were established on this continent and in Europe.

There is no sharp line of demarcation between the hard-wheat and the soft-wheat regions in the United States. The line of demarcation lies in the approximate vicinity of the 95th meridian, but hard wheats are produced east of, and soft wheats are grown west of, this division line. There is an overlapping zone in which neither type is grown exclusively. As a consequence, soft wheats may be grown under conditions tending to produce a protein content higher than usual, and hard wheats may be grown under conditions tending to produce much lower protein than is customary. It is in this overlapping zone that the greatest difficulty is experienced with these two types or classes of wheat. The Eastern third of Kansas is within this area, and thus the problem is one of importance to this state.

It has been generally accepted as proved that the soft red winter wheats as a class are not only different in milling properties from the hard red winter and the hard red spring wheats, but also inferior to them in bread-making quality. This fact has been shown by the extensive investigations of Thomas (1917), Shollenberger (1923), Shollenberger and Clark (1924), Coleman *et al.* (1930), and the less extensive studies made by Pelshenke (1933), Geddes (1937) and others. Some of the data obtained by Thomas (1917) and by Shollenberger (1923) are shown in graphical form in Figure 1, and indicate that at all protein levels the soft red winter wheat flours gave lower loaf volumes than either the hard spring or hard winter wheat flours. Compared to either of these classes of hard wheats, the soft wheats would have to be regarded as definitely inferior. The average values given by Shollenberger and Clark (1924) are much less convincing. They show, for instance, that the hard spring wheats averaged 13.6% protein and 2,142 cc. in loaf volume, while the corresponding values for soft red winter wheats were 11.3% and 2,001 cc., respectively. It can be seen that the soft red winters although 16.9% lower in protein were only 6.6% lower in loaf volume than the hard red spring wheats of this series, thus making it appear that the soft wheats were of better quality intrinsically than the other classes of wheat represented. There is a contradiction in conclusions from these data and those of Shollenberger's (1923) earlier publication.

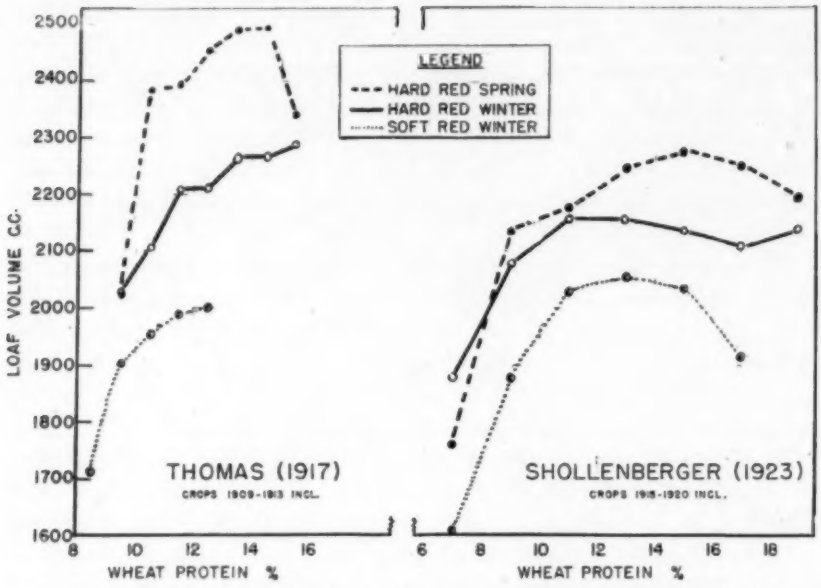

Fig. 1. Relation of loaf volume to wheat protein content for three classes of United States wheat.

A summary of the data of Coleman *et al.* (1930) is given in Table I. Here again, as in Shollenberger and Clark's (1924) data, it might be concluded that the loaf volumes of the soft red winter wheat flours were greater than they should have been for the protein content. Calculated from the hard red spring values, the volume at 10.26% protein would be expected to be 1,731 cc. instead of 2,152 cc., which it was. The soft red winter samples were, on the average, 0.2% lower in loaf volume although they were 19.7% lower in protein content. The only criticism of the baking performance of the soft wheats was

TABLE I

A Summary of the Data Obtained with Export Cargo Samples of Various Classes of United States Wheat
From the data of Coleman *et al.* (1930)

Class	No. samples	Wheat protein	Loaf volume	Crumb		Break and shred	Loaf vol. per unit protein[1]
				Color	Grain		
		%	cc.				
Hard red spring	14	12.78	2156	87	91	Good	169
Hard red winter	34	10.91	2176	88	91	Fair	199
Soft red winter	40	10.26	2152	89	89	Poor	210
White wheat	30	10.94	2074	88	88	Fair	190

[1] Calculated from the data. Not in original data.

that the break and shred were poor as compared to "fair" for the hard winters and "good" for the hard spring wheat samples.

From Figure 1 it would seem that average values of samples covering a wide range of protein content ought to be accepted with some reservations. They may be vitiated by failure to get the loaf volume expected by high protein samples. It has been demonstrated by Larmour (1931), Geddes and Larmour (1933), Aitken and Geddes (1934), Geddes (1937), and others that with proper baking formulas the loaf volume of hard spring wheat flours is a linear function of the protein content. Larmour, Working, and Ofelt (1939) have shown that this applies also to the hard winter wheats. The earlier baking methods did not show this. On the contrary, the data of Thomas (1917) and Shollenberger (1923) indicate generally that the increase in loaf volume was not proportional to the increase in protein above a certain value. The higher protein samples were apparently no better and sometimes distinctly poorer than those of medium protein content. Consequently the average values obtained from such data would be influenced to different extents, depending on the relative proportion of samples falling in the high-protein classes. Therefore graphical representation such as shown in Figure 1 is more reliable than general averages.

Considering what is now known about experimental baking methods for both hard spring and hard winter wheats, it is doubtful that much reliance ought to be placed upon the earlier baking data which were obtained by the use of rather lean formulas, quite inadequate for use with high-protein samples. It was considered a matter of interest to see how far this applied to the soft red winter wheats.

Little has been published concerning the soft wheats of Kansas, because they represent a relatively small fraction of the total wheat production of the state. The Kansas State Board of Agriculture estimated that 8.3% of the total wheat acreage of Kansas was planted to soft winter wheats in 1937. The percentage production would be somewhat higher, because the soft wheats are grown principally in the eastern part of the state, where rainfall is relatively abundant and average yields are high.

The principal varieties grown are Kawvale, Clarkan, Harvest Queen, Michigan Wonder, Fulcaster, and Currell. The acreage sown to Kawvale exceeds that of all other soft varieties combined. In 1937 it amounted to 5.1% of the total wheat acreage in Kansas, or slightly more than 60% of the soft wheat acreage. Kawvale is a selection from Indiana Swamp, an old variety of limited distribution and is classed as a "semi-hard" wheat. Because Kawvale has good agronomic characteristics, it is grown over a fairly wide area and has caused

considerable difficulty from the standpoint of grading. Clarkan, Michigan Wonder, and Harvest Queen are typical soft wheats which meet the requirements of the soft-wheat millers quite satisfactorily. Of the three, Clarkan has the best agronomic characteristics and is the variety recommended for eastern Kansas.

Materials and Methods Used

An excellent series of samples was obtained through the courtesy of A. L. Clapp of the Department of Agronomy of Kansas State College. The samples were grown in demonstration plots from seed supplied by the college; the harvesting and threshing were supervised by the college. The individual samples were first analyzed for protein, then combined into composites of various protein levels. The range of protein was not great, as the samples were grown in the area of higher rainfall, characteristic of the soft wheat regions.

The technique of testing was similar to that described in detail for Kansas hard winter wheats by Larmour, Working, and Ofelt (1939). For convenience the two baking formulas used are given in Table II.

TABLE II

INGREDIENTS USED IN BAKING FORMULAS I AND II

Ingredients	Percentage based on flour	
	Formula I	Formula II
Yeast	2	2
Sugar	6	6
Shortening	3	3
Salt	1.50	1.75
Dry-milk solids	4	6
Potassium bromate	0.001	0.003[1]
Water	As required	As required
Malt syrup (120° l.)	0.25	—
Ammonium phosphate	0.05	—

[1] Except with Kawvale and Turkey. With these 0.004% potassium bromate was used.

The doughs were mixed to optimum consistency, fermented three hours at 30° and proofed 55 minutes at the same temperature. They were baked 25 minutes at 232°C. The doughs were mixed in the Swanson-Working mixer, punched by means of National sheeting rolls, and molded in a Thompson laboratory molder.

Wheat-meal-fermentation time of the composite samples was determined by the method described by Swanson (1937), using 0.78 g. compressed yeast for each 15 g. meal.

Protein content, baking data by two formulas, wheat-meal-fermentation time, together with corresponding data for Turkey composites of the same protein range, are given in Table III.

TABLE III

BAKING DATA AND DESCRIPTION OF SAMPLES

Variety	Flour protein	Formula I		Formula II		Wheat-meal-fermentation time
		Loaf vol.	Texture score	Loaf vol.	Texture score	
	%	*cc.*		*cc.*		*min.*
Clarkan	9.1	668	6.3	665	7.0	38
	10.4	665	5.9	705	7.0	41
	11.6	628	5.6	700	7.5	53
Harvest Queen	8.9	625	4.5	630	6.5	35
	10.1	668	4.9	700	7.0	36
	11.3	645	4.9	705	7.0	37
	11.7	655	5.6	715	7.0	39
Michigan Wonder	9.0	665	5.2	660	8.0	27
	9.6	712	5.2	715	8.0	34
	10.6	728	5.2	755	8.5	35
	12.0	725	4.9	765	8.5	39
Kawvale	10.1	700	7.7	723	9.5	58
	11.3	762	8.4	800	9.5	59
	13.0	752	8.1	863	9.5	63
	14.2	770	8.1	913	9.5	98
Turkey	8.2	708	8.3	658	8.0	23
	9.5	708	8.3	733	8.0	40
	10.1	752	9.0	743	8.5	57
	11.0	785	9.4	798	9.5	52
	11.7	822	9.1	843	9.5	49
	13.2	812	9.4	898	9.0	93

Baking Data

Loaf volumes obtained by the two formulas for each of the varieties indicated in Table III are shown graphically in Figure 2. There was little difference in the loaf volumes obtained by the two formulas with the lowest protein samples of each variety. This indicates at least that the higher dosage of bromate in Formula II did not damage the lower-strength flours in the series. The beneficial effect of the combination of increased milk and increased bromate is shown in the higher-protein samples of each variety. While the relation of loaf volume to protein content of flour was not linear over the whole range of protein, it more closely approached linearity with baking Formula II. The increased milk and bromate benefited the high-protein flours more than those of low protein in each series.

Loaf volumes by Formula II are plotted against protein of flour in Figure 3. The resemblance of Kawvale to Turkey is evident. Michigan Wonder gave greater loaf volumes than either Clarkan or Harvest Queen. The two latter varieties were approximately equal and much lower than Turkey of corresponding protein content. There is no

doubt that these two soft wheat varieties were distinctly inferior to both Turkey and Kawvale in *inherent baking quality*. Michigan Wonder was somewhat higher in quality but not equal to Turkey.

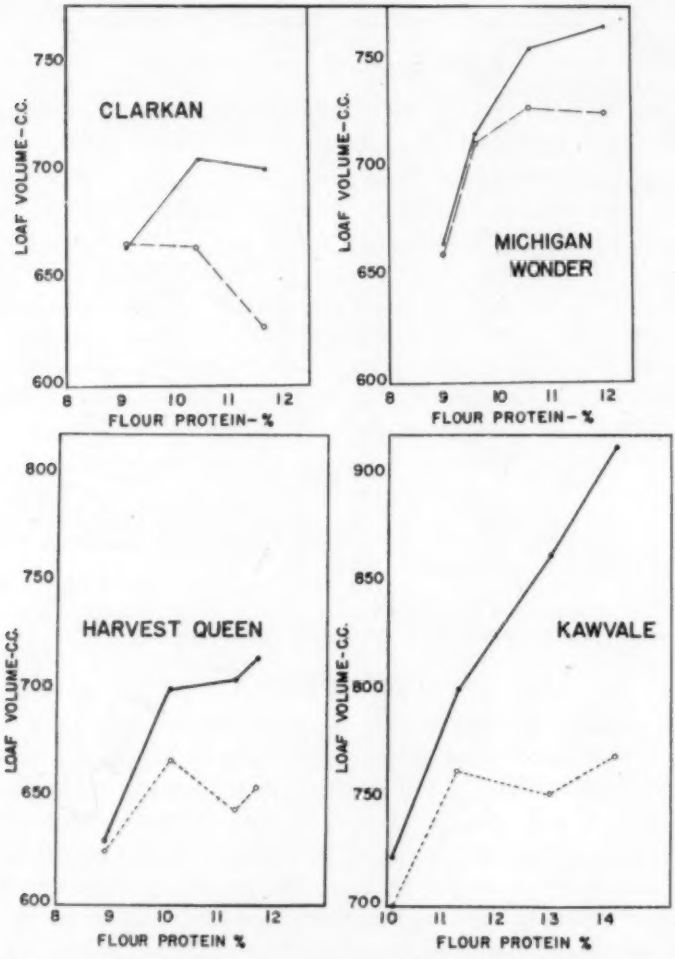

Fig. 2. Relation of loaf volume to flour protein content, for four varieties of Kansas wheat, crop of 1938. Broken graph represents Formula I, solid graph Formula II.

Physical Characteristics of the Dough

All samples were mixed on the Swanson-Working recording micro-mixer and the curves so obtained are shown in Figure 4. The three soft wheats, Clarkan, Michigan Wonder and Harvest Queen, show some common characteristics, whereas the curves for Kawvale are distinctly different and resemble those obtained with Turkey. The soft-wheat

curves rise very abruptly to a maximum in about one minute and then fall off rather rapidly in both height and width. Kawvale on the contrary gives a relatively slow rise to the maximum, followed by a more gradual drop, which is not accompanied by the very rapid narrowing of the band shown by the other three varieties. These Kawvale curves indicate that the dough characteristics are closely related

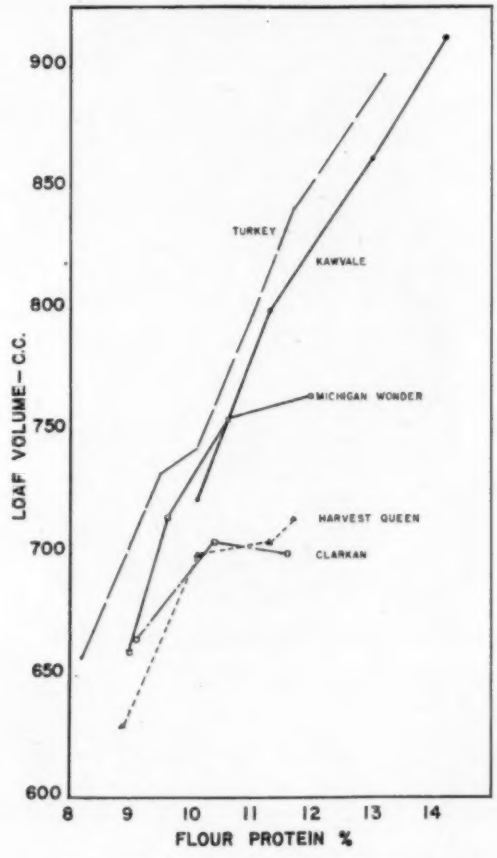

Fig. 3. Loaf volumes obtained by Formula II.

to the haru winter wheats with respect to mixing behavior of the dough. Kawvale is unquestionably differentiated qualitatively from soft wheats. The soft wheats exhibit quite distinctive dough characteristics throughout the range of protein studied, and there seems little doubt that this characteristic may be used to distinguish this class from the hard wheats.

Wheat-Meal-Fermentation-Time Test

There is no unanimity of opinion as to the usefulness of the wheat-meal-fermentation-time test in differentiating wheats in respect to quality. Pelshenke (1933), Cutler and Worzella (1931, 1933), and Swanson and Dines (1939) have used this method to classify wheats, on the assumption that the length of time is directly related to the

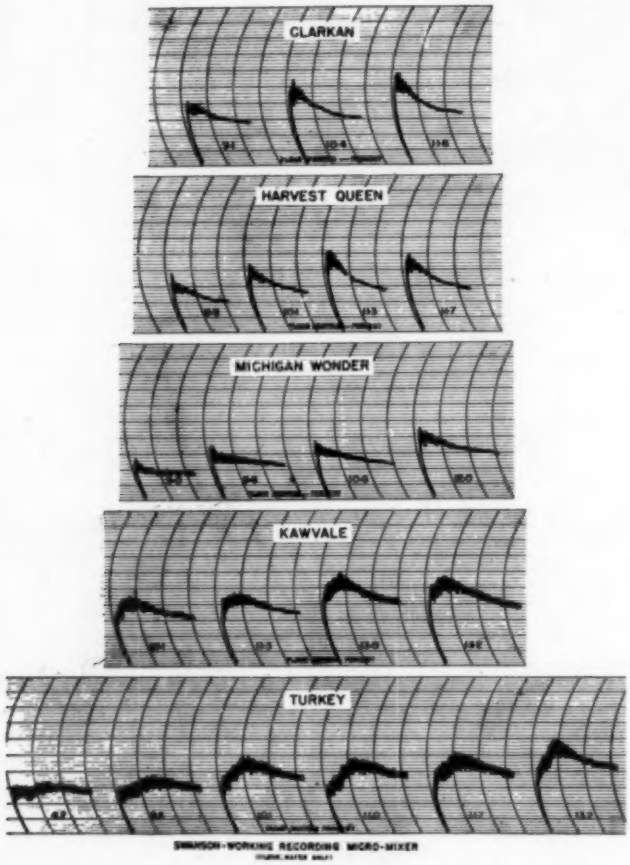

Fig. 4. Curves obtained by the Swanson-Working recording micro-mixer—flour-water doughs.

baking quality. While this may be true over the whole range of bread wheats, which includes a number of distinct classes, there is a considerable amount of overlapping, which makes it difficult to draw very fine distinctions. It is generally accepted that the hard spring wheats exhibit very long times, the hard winter wheats intermediate times, and the soft wheats rather short times. These relative values can be seen in the tables given by Pelshenke (1933) and Geddes (1937.)

The data in Table III for Kansas wheats and the graphs in Figure 5 show that Clarkan, Harvest Queen, and Michigan Wonder tend to be somewhat shorter in time than Kawvale or Turkey. It should be noted, however, that the low-protein Turkey samples exhibited times quite comparable to those of the typical soft wheats. The principal difference between Kawvale and Turkey on the one hand, and Clarkan, Harvest Queen, and Michigan Wonder on the other, is that at protein contents of about 10% the former rise to a substantially

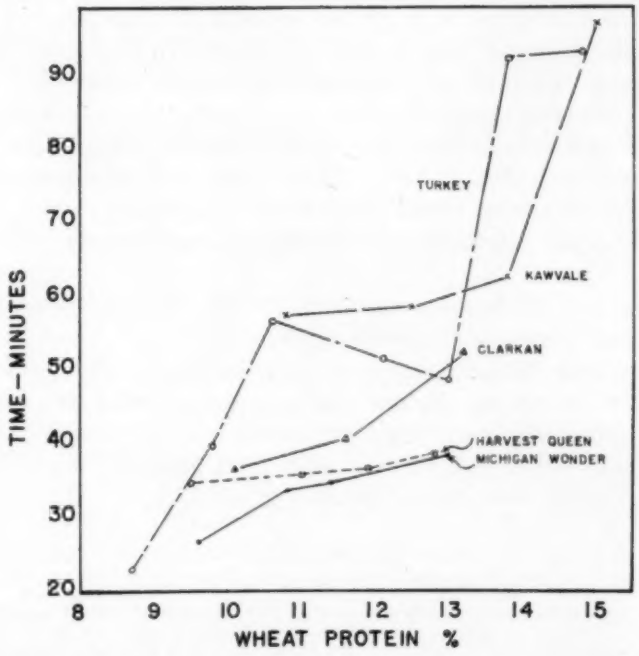

Fig. 5. Relation of wheat-meal-fermentation time to wheat protein content. Number of minutes that elapse from the moment the doughball is put into the water until it starts to disintegrate at the dough-water interface.

higher level of times. Unfortunately no high-protein samples of the latter three varieties were available, and therefore one cannot say that they would not give high time values at high protein contents. From the appearance of the curves, it would seem that Harvest Queen and Michigan Wonder were flattening out, but one can only surmise what might happen in the case of Clarkan, which appears to show increased times throughout its limited range of protein. It might be of interest to add here that Turkey wheat of 17.1% protein content gave a time of 110 minutes, a value comparable to that often obtained with hard spring wheat. There seems no doubt that Kawvale shows the same

magnitude of time as Turkey, and cannot be differentiated from it in this respect.

Summary and Conclusion

Kawvale, a semi-hard winter variety, appears to be distinctly differentiated from the typical soft varieties Clarkan, Harvest Queen, and Michigan Wonder. It resembles Turkey in wheat-meal-fermentation time, baking performance, and to some extent in mixing-curve characteristics. These similarities were observed over the protein range from 10.7% to 15.0%.

Clarkan, Harvest Queen, and Michigan Wonder were lower in baking quality than either Kawvale or Turkey of comparable protein levels. The latter two were substantially lower in whole-wheat-meal-fermentation time than Turkey, particularly at their upper protein levels which were about 13.0%. They were most distinctly different from Turkey in respect to the character of their mixing curves, showing very rapid development, sharp rapid decline, and early thinning of the curves.

Baking tests of the soft-wheat varieties did not give a linear relation between loaf volume and protein content, the loaf volume tending to fall off at about 10% flour protein. Somewhat better relationship of these variables was obtained with 3 mg. potassium bromate and 6% dry milk solids than with 1 mg. potassium bromate and 4% dry milk solids. This would indicate the need for testing the higher-protein soft-wheat flours with greater dosages of bromate.

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FAT ACIDITY IN RELATION TO HEATING OF CORN IN STORAGE

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Spontaneous heating is an ever-present hazard in the storage and shipment of grain. Grain that has been allowed to heat is invariably damaged to some extent. The degree of damage may be imperceptible if the heating is arrested in its very early stages, or it may account for an almost complete loss in commercial value if allowed to progress unchecked.

Spontaneous heating is caused by the heat liberated in the process of respiration, not only of the grain itself but of certain fungi and bacteria proliferating on the surface of the kernels. Whenever conditions are such that heat is produced more rapidly than it is lost by conduction and radiation, the temperature will rise; and since within certain limits the rate of respiration increases with rise in temperature, spontaneous heating once started may become rapidly accelerated.

The rate of respiration, and hence the rate at which heat is developed, depends upon the moisture content of the grain, the temperature, the available oxygen supply, and upon certain characteristics of the grain itself which are not completely understood. Bailey (1921) and Bailey and Gurjar (1918) have made a careful study of the relation of moisture and temperature to rate of respiration in corn and wheat.

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These authors have shown that in the case of damp wheat not only the actual moisture content but the length of time the grain has been stored in a damp condition influence the rate of respiration. They also have shown that grain that has been damaged from various causes respires at a more rapid rate than does sound grain at the same temperature and moisture content.

In commercial practice it has been observed repeatedly that different lots of grain of equal moisture content often display quite different tendencies to heat under similar conditions of storage. Grain having a moisture content that would ordinarily be considered at a safe level for storage sometimes heats within a relatively short time. Other lots of grain at considerably higher moisture levels may remain cool and sweet for an extended period of storage. Obviously, some method for determining this difference in condition between different lots of grain stored under comparable conditions, which would enable storage behavior to be predicted with greater accuracy than can be done from the moisture content alone, would be of considerable practical value.

Experimental

It has been shown by Zeleny and Coleman (1938, 1939) that the fat acidity of grain, particularly of corn, is a more reliable measure of its degree of soundness than other available chemical or physical tests. In order to test experimentally the value of this determination as a measure of storage behavior, 122 samples of commercial corn, ranging in moisture content from 15.5% to 27.3%, were obtained from Federal Grain Supervision offices in different parts of the country. Cracked corn and foreign material were removed from the samples by appropriate sieving, and representative portions of the clean corn were taken for moisture and fat-acidity determinations. Moisture determinations were made by the water-oven method specified by the Official Grain Standards of the United States (1935). Fat-acidity determinations were made by the method of Zeleny and Coleman (1938, 1939) and were expressed in terms of milligrams of potassium hydroxide required to neutralize the free fatty acids extracted from 100 g. of corn, calculated to a dry-matter basis.

For the heating tests one-quart vacuum bottles were nearly filled with corn, thermometers were inserted to about the middle of the bottles, and loose wads of cotton were inserted in the necks, thus insuring a sufficient interchange of gases to support respiration. The corn, bottles, and thermometers were all preheated to 90°F. before starting the tests. The bottles after filling were placed in an incubator regulated at 90°F. Temperature readings were taken at appropriate intervals, depending on the rate of temperature increase. Rate of heating

was expressed in terms of the number of degrees Fahrenheit increase in temperature above 90°F. per 24 hours. In the case of samples which heated less than 5°F. above 90°F. in 72 hours, the average increase in temperature per 24 hours for the first 72 hours was taken as the rate of heating. For samples which heated more than 5°F. above 90°F. in 72 hours, the rate of heating per 24 hours was calculated from the time required for the sample to heat from 90°F. to 95°F., since at temperatures above 95°F. heat losses were sufficiently great to make temperature readings an unreliable index of the heat produced. In Table I are listed the values for moisture content, fat acidity, and rate of heating obtained for the 122 samples included in this study.

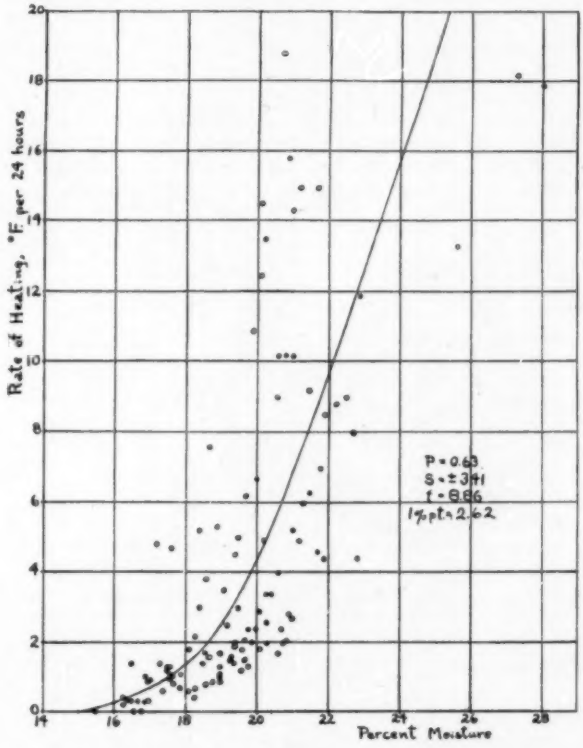

Fig. 1. Relation between moisture content and rate of heating in experimental storage of 122 samples of corn.

Interpretation of Results

In Figure 1 is shown the relationship between moisture content and rate of heating for the series of samples under investigation. Whereas a general relationship between these two factors is evident, it is obviously not possible to predict reliably the rate of heating of any given

sample from its moisture content. At any given moisture level, however, it may be shown that the rate of heating tends to increase for increasing values of fat acidity. Thus when the rate of heating is plotted against the quantity $M+.05F$, where M is the percentage of moisture and F is the fat-acidity value (Fig. 2), we obtain a much closer relationship than we did between rate of heating and moisture alone.

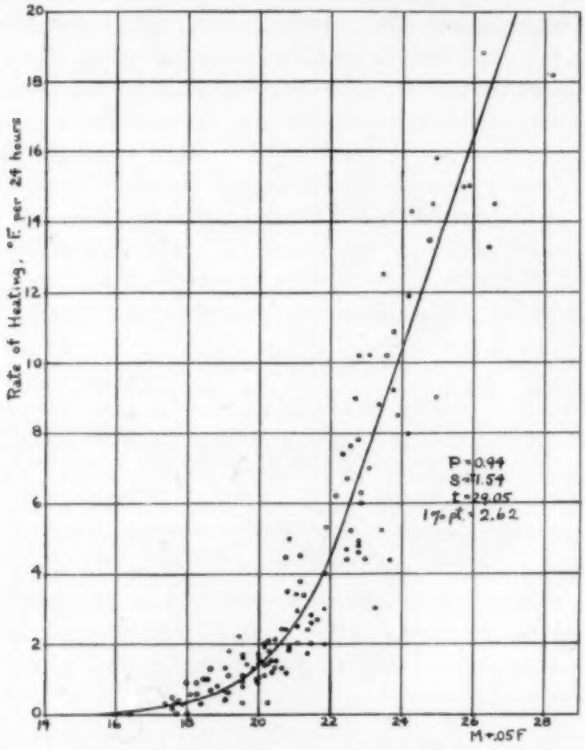

Fig. 2. Relation between $M + .05F$ (where M is the moisture content and F is the fat acidity value) and rate of heating in experimental storage of 122 samples of corn.

Statistical analysis of these relationships yields the following results:

	Index of correlation	Standard error of estimate °F.	t	1% point
Rate of heating and moisture (Fig. 1)	0.63	±3.41	8.86	2.62
Rate of heating and $M+.05F$ (Fig. 2)	0.94	±1.54	29.05	2.62

It is evident from these values that in any series of corn samples similar to the series under investigation, the rates at which the samples will undergo spontaneous heating under controlled conditions similar to those herein employed, may be predicted with more than twice the

TABLE I

MOISTURE CONTENT, FAT ACIDITY, AND ACTUAL AND PREDICTED RATES OF SPONTANEOUS HEATING OF 122 SAMPLES OF CORN

Moisture	Fat acidity	H[1]	H_M[2]	$H_M - H$	H_{MF}[3]	$H_{MF} - H$
%		° F.	° F.	° F.	° F.	° F.
15.5	18	0.0	0.1	+0.1	0.1	+0.1
16.3	26	0.2	0.4	+0.2	0.2	0.0
16.3	30	0.4	0.4	0.0	0.3	−0.1
16.4	20	0.3	0.4	+0.1	0.2	−0.1
16.5	29	0.3	0.4	+0.1	0.3	0.0
16.5	77	1.4	0.4	−1.0	1.6	+0.2
16.6	29	0.0	0.5	+0.5	0.3	+0.3
16.7	20	0.3	0.5	+0.2	0.3	0.0
16.7	32	0.6	0.5	−0.1	0.4	−0.2
16.7	18	0.5	0.5	0.0	0.2	−0.3
16.8	19	0.0	0.6	+0.6	0.3	+0.3
16.9	31	0.3	0.6	+0.3	0.4	+0.1
16.9	63	1.0	0.6	−0.4	1.3	+0.3
17.0	52	0.3	0.7	+0.4	1.0	+0.7
17.0	66	0.3	0.7	+0.4	1.6	+1.3
17.0	27	0.9	0.7	−0.2	0.4	−0.5
17.0	20	0.9	0.7	−0.2	0.3	−0.6
17.2	112	4.8	0.8	−4.0	6.9	+2.1
17.3	48	1.4	0.9	−0.5	1.1	−0.3
17.4	15	0.6	0.9	+0.3	0.4	−0.2
17.5	65	1.2	1.0	−0.2	2.2	+1.0
17.5	24	1.3	1.0	−0.3	0.5	−0.8
17.6	19	1.0	1.1	+0.1	0.5	−0.5
17.6	20	1.0	1.1	+0.1	0.5	−0.5
17.6	41	1.1	1.1	0.0	1.0	−0.1
17.6	47	1.3	1.1	−0.2	1.3	0.0
17.6	99	4.7	1.1	−3.6	6.0	+1.3
17.7	24	0.8	1.2	+0.4	0.6	−0.2
17.9	17	0.7	1.3	+0.6	0.5	−0.2
17.9	27	1.1	1.3	+0.2	0.8	−0.3
18.0	23	1.3	1.4	+0.1	0.7	−0.6
18.1	23	0.6	1.5	+0.9	0.8	+0.2
18.1	23	1.8	1.5	−0.3	0.8	−1.0
18.3	17	0.4	1.7	+1.3	0.7	+0.3
18.3	17	0.7	1.7	+1.0	0.7	0.0
18.3	25	2.2	1.7	−0.5	1.0	−1.2
18.3	98	4.0	1.8	−2.2	8.1	+4.1
18.4	103	5.2	1.8	−3.4	8.9	+3.7
18.5	30	1.4	1.9	+0.5	1.4	0.0
18.6	21	0.8	2.0	+1.2	1.0	+0.2
18.6	21	1.7	2.0	+0.3	1.0	−0.7
18.6	52	3.8	2.1	−1.7	2.8	−1.0
18.7	18	1.6	2.2	+0.6	1.0	−0.6
18.7	78	7.6	2.2	−5.4	6.3	−1.3
18.8	16	0.9	2.3	+1.4	1.0	+0.1
18.9	60	5.3	2.5	−2.8	4.3	−1.0

[1] Observed rate of heating, ° F. per 24 hours.
[2] Rate of heating predicted from moisture content (Fig. 1).
[3] Rate of heating predicted from $M + .05F$ (Fig. 2).

TABLE I—*Continued*

Moisture	Fat acidity	H[1]	H_M[2]	$H_M - H$	H_{MF}[3]	$H_{MF} - H$
%		° F.	° F.	° F.	° F.	° F.
19.0	21	0.9	2.6	+1.7	1.4	+0.5
19.0	25	1.1	2.6	+1.5	1.5	+0.4
19.0	31	1.3	2.6	+1.3	1.8	+0.5
19.0	21	1.7	2.6	+0.9	1.4	−0.3
19.0	20	1.0	2.6	+1.6	1.4	+0.4
19.1	34	3.5	2.8	−0.7	2.2	−1.3
19.2	39	2.5	3.0	+0.5	2.7	+0.2
19.3	17	1.5	3.1	+1.6	1.5	0.0
19.3	14	1.6	3.1	+1.5	1.4	−0.2
19.4	16	1.4	3.3	+1.9	1.5	+1.0
19.4	16	1.9	3.3	+1.4	1.5	−0.4
19.4	16	2.0	3.3	+1.3	1.5	−0.5
19.4	29	4.5	3.3	−1.2	2.2	−2.3
19.4	37	4.5	3.3	−1.2	2.8	−1.7
19.5	20	2.1	3.5	+1.4	1.8	−0.3
19.5	18	1.5	3.5	+2.0	1.7	+0.2
19.5	49	3.0	3.5	+0.5	4.3	+1.3
19.5	28	5.0	3.5	−1.5	2.4	−2.6
19.6	16	1.2	3.7	+1.5	1.7	+0.5
19.6	14	1.8	3.7	+1.9	1.6	−0.2
19.7	16	1.5	3.9	+2.4	1.8	+0.3
19.7	13	2.1	3.9	+1.8	1.6	−0.5
19.7	51	6.2	3.9	−2.3	5.0	−1.2
19.8	19	1.3	4.1	+2.8	2.1	+0.7
19.8	18	2.4	4.1	+1.7	2.1	−0.3
19.9	78	10.9	4.3	−6.6	9.9	−1.0
19.9	20	1.9	4.3	+2.4	2.4	+0.5
19.9	20	2.4	4.3	+1.9	2.4	0.0
20.0	17	2.4	4.5	+2.1	2.2	−0.2
20.0	51	6.7	4.5	−2.2	6.0	−0.7
20.0	61	4.4	4.5	+0.1	7.5	+3.1
20.0	133	14.5	4.5	−10.0	18.2	+3.7
20.1	17	1.8	4.7	+2.9	2.4	+0.6
20.1	21	2.9	4.7	+1.8	2.7	−0.2
20.1	69	12.5	4.7	−7.8	9.0	−3.5
20.1	96	14.5	4.7	−9.8	13.1	−1.4
20.2	40	4.9	5.0	+0.1	5.0	+0.1
20.2	92	13.5	5.0	−8.5	12.8	−0.7
20.3	17	2.0	5.2	+3.2	2.7	+0.7
20.3	25	2.6	5.2	+2.6	3.3	+0.7
20.3	16	3.4	5.2	+1.8	2.7	−0.7
20.4	19	3.4	5.5	+2.1	3.0	−0.4
20.6	17	1.7	6.0	+4.3	3.2	+1.5
20.6	27	4.0	6.0	+2.0	4.3	+0.3
20.6	42	9.0	6.0	−3.0	6.6	−2.4
20.6	45	10.2	6.0	−4.2	6.9	−3.3
20.7	14	2.4	6.3	+3.9	3.2	+0.8
20.7	113	18.8	6.3	−12.5	17.3	−1.5
20.8	14	2.0	6.6	+4.6	3.3	+1.3
20.8	22	2.0	6.6	+4.6	4.3	+2.3
20.8	33	7.4	6.6	−0.8	5.7	−1.7
20.8	46	10.2	6.6	−3.6	7.8	−2.4
20.8	41	7.8	6.6	−1.2	6.9	−0.9
20.9	12	2.8	7.0	+4.2	3.3	+0.5
20.9	83	15.8	7.0	−8.8	13.5	−2.3

TABLE I—*Continued*

Moisture	Fat acidity	H[1]	H_M[2]	$H_M - H$	H_{MF}[3]	$H_{MF} - H$
%		° F.	° F.	° F.	° F.	° F.
21.0	14	2.7	7.1	+4.4	3.8	+1.1
21.0	33	5.2	7.1	+1.9	6.3	+1.1
21.0	53	10.2	7.1	−3.1	9.3	−0.9
21.0	66	14.3	7.1	−7.2	11.3	−3.0
21.2	32	4.9	7.6	+2.7	6.9	+2.0
21.2	93	15.0	7.6	−7.4	15.8	+0.8
21.3	32	6.0	7.9	+1.9	7.2	+1.2
21.5	28	6.3	8.4	+2.1	7.2	+0.9
21.5	46	9.2	8.4	−0.8	9.9	+0.7
21.7	18	4.6	8.7	+4.1	6.9	+2.3
21.7	84	15.0	8.7	−6.3	16.1	+1.1
21.8	27	7.0	9.3	+2.3	7.8	+0.8
21.9	13	4.4	9.6	+5.2	6.0	+1.6
21.9	41	8.5	9.6	+1.1	10.1	+1.6
22.2	25	8.8	10.5	+1.8	8.7	−0.1
22.5	50	9.0	11.4	+2.4	13.5	+4.5
22.7	31	8.0	12.0	+4.0	11.1	+3.1
22.8	18	4.4	12.3	+7.9	9.6	+5.2
22.9	27	11.9	12.6	+0.7	11.1	−0.8
25.6	19	13.3	21.2	+7.9	17.9	+4.6
27.3	21	18.2	26.2	+8.0	23.1	+4.9

accuracy when both moisture content and fat acidity are considered than when moisture content is considered alone. This is further illustrated by the data in the last four columns of Table I showing the rates of heating as predicted from the moisture content and as predicted from both fat acidity and moisture, together with the differences between predicted and actual rates of heating.

Figure 3 shows graphically the relationships between fat acidity, moisture content, and rate of heating, which apply under the experimental conditions used. These curves are derived from the curve in Figure 2 by substituting specific values for M and F, and serve to illustrate the value of the fat-acidity determination as an index of storage behavior. Thus it may be seen, for example, that under carefully controlled conditions corn with a moisture content of 17% and a fat-acidity value of 100 can be expected to heat in storage as rapidly as corn with a moisture content of 21% and a fat-acidity value of 20.

It is not contended that the presence of free fatty acids as such in corn in any way affects its rate of respiration, and thus its tendency to heat. Fat acidity should be considered merely as a useful index of more obscure chemical, physical, or biological changes occurring during the deterioration of corn that appear to stimulate its rate of respiration. It must be conceded that the rather limited number of samples in-

cluded in this study does not preclude the possibility that under certain conditions respiration of corn at a given moisture level might be stimulated without an increase in fat acidity, or that fat acidity might increase greatly without a corresponding increase in respiration. No such instances, however, have appeared in this study.

It should be emphasized that the curves in Figure 3 may be used for predicting rates of heating only for corn in experimental storage under a given set of conditions, and that it is not probable that the same curves would be applicable to corn in commercial storage. It is reasonable to expect, however, that under any normal storage condi-

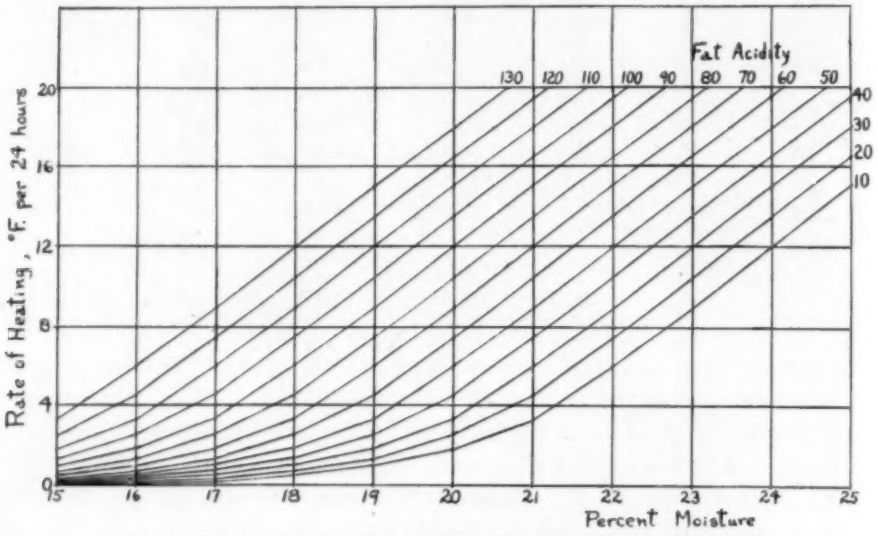

Fig. 3. Relation between moisture content, fat acidity, and rate of heating for corn in experimental storage.

tions, either commercial or experimental, analogous relationships between moisture content, fat acidity, and rate of heating will hold, and that low-acidity corn may be as good a commercial storage risk as high-acidity corn containing as much as 4% less moisture. Safe fat-acidity limits for the commercial storage of corn at different moisture levels cannot be determined solely by laboratory experimentation, but only through the extensive practical application of the fat-acidity test to corn in storage and the observation of its relationship to storage behavior.

It is anticipated that such data will gradually be accumulated through the cooperation of interested commercial laboratories, and that this cooperative effort may lead eventually to the establishment of useful fat-acidity limits at different moisture levels for the safe commercial storage of corn and possibly of other cereal grains.

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PLASTICITY OF DOUGHS [1]

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Various methods have been employed for determining the relative plasticity of doughs, and particularly as this property is related to the measurement of the water absorption of flour and other dough ingredients. Several of the devices employed for that purpose are described by Markley and Bailey (1938). Sharp (1926) used a pressure plastometer for studying the rate of flow through a fine capillary of flour-in-water suspensions. A yield value was observed with 19% or more of flour by weight, thus indicating a plastic system, but Sharp did not use concentrations over 33% flour and hence did not operate within the limits of plasticity of doughs ordinarily encountered in bread doughs. St. John and Bailey (1929) also used a pressure plastometer and studied the rate of flow of flour-water suspensions. They likewise employed suspensions much higher in water content than ordinary doughs.

Halton and Scott Blair (1936b) extruded doughs from a "gun," using a weight of seven pounds in a study of various physical properties of doughs. Halton and Fisher (1938) describe a dough plastometer which measures the rate of extrusion through an aperture. Pressure was applied to the dough by a piston resting on the dough surface. This piston was attached to a weight suspended by a fine wire which passed through the aperture in the bottom of the cylinder in which the dough was contained.

The instrument described here is based on the principles of the pressure plastometers and intended for doughs in a range of plasticity generally used for baking.

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The Apparatus

Figure 1 is a diagram of the apparatus. The main air-pressure valve is shown at *A*, and *B* is a diaphragm-type pressure regulator used to maintain a constant pressure as indicated by *C*, the mercury manometer.

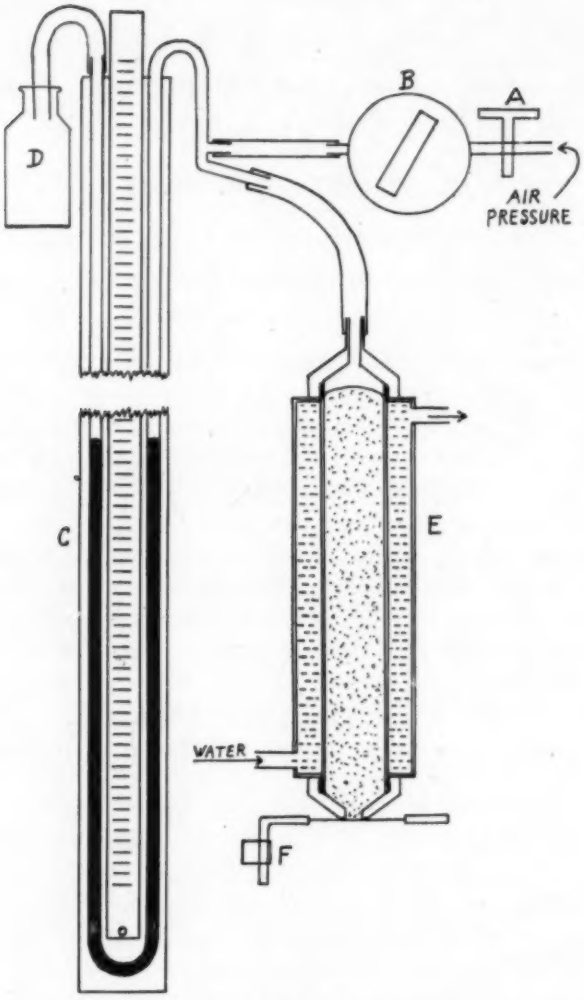

Fig. 1. Diagram of the pressure plastometer.

The extrusion apparatus (*E*) is provided with a water jacket similar to a Liebig condenser through which water at constant temperature from a water thermostat is circulated by means of a centrifugal pump. The dough cylinder is 22 mm. in diameter and 170 mm. long, the

jacket cylinder 44 mm. in diameter and about 140 mm. long. Both cylinders are made from brass pipe. The top and the bottom of the dough cylinder are threaded and can easily be removed for filling and also for cleaning by means of a tight-fitting plunger. The opening at the bottom is exactly 6 mm. in diameter and the thickness of the bottom cap through which this aperture is bored is 6 mm.

A fine wire (*F*) is mounted on a frame so that it can swing back and forth for cutting the extruded dough sharply at the aperture. The bottle (*D*) receives any overflow of mercury which results from inadvertently increasing the pressure unduly when adjusting the valves to the desired pressures.

Doughs were made from 100 g. of flour (13.5% moisture), 2 g. of salt and the necessary water, and were mixed for two minutes in the Hobart-Swanson mixer. About 75 g. of dough were required to fill the apparatus, and this was done within 30–45 seconds after the mixing was completed. The dough was rolled into a long cylinder, immediately introduced through the top opening of the dough cylinder, and then packed down with the plunger. A series of preliminary tests indicated that the results were most constant when the dough was allowed to rest in the cylinder for five to six minutes. The rate of flow was slower with less than five minutes of rest in the cylinder, but it was practically constant after five and up to 12 minutes. It was necessary to introduce the dough into the cylinder at a temperature within one degree of that required for the test. The temperature of the dough could be determined by removing the rubber tubing from the upper cap and inserting a thermometer. With the aperture of 6 mm. a pressure of 500 mm. of mercury was found to be most satisfactory with doughs of ordinary plasticity.

After the five- to six-minute resting period which followed the introduction of the dough into the cylinder, the pressure was applied through valve *A* and adjusted with valve *B*. The latter had previously been set for the desired pressure and only minor adjustments were necessary after the pressure was applied. About four to five grams of dough was allowed to flow out, after which the dough was cut at the same instant that a stop-watch was started. The dough was allowed to flow for one minute into a tared pan, and the quantity of extruded dough was immediately weighed to the nearest centigram.

It is quite important that four to five grams of dough be allowed to flow out of the cylinder before the test is started. Only the rate of flow for the first minute thereafter was used, since the second minute of flow did not afford close replicates and particularly with the slacker doughs when the air sometimes broke through.

Closest replicates were obtained when the plasticity of the dough was within the limits of flow of two to ten grams per minute. Slacker doughs gave best results by measuring the flow for one-half minute and recording double that weight for the equivalent of the standard one-minute flow. The most difficult operation in securing replicated results in close agreement involved the control of the degree of compactness of the dough as it was rolled out to be placed in the apparatus. Air pockets in the dough must be carefully avoided. After some experience the results can be replicated quite satisfactorily by the operator.

Experimental

The effects of temperature and pressure upon the plasticity of dough were studied with a flour containing 11.60% crude protein (N×5.7) and a constant proportion of water equivalent to 60%. The pressure used was 500 mm. of mercury in the study of temperature variations, and the temperature of the dough was 30°C. in the study of pressure variations. The results of these tests are shown graphically in Figure 2. A variation in temperature of one degree changed the rate of flow about 0.29 g. per minute, thus indicating that temperature control was essential to secure comparable results. A variation in pressure of 10 mm. changed the rate of flow only about 0.17 g. per minute, and the pressure was easily controlled to within ±2 mm. during a test. It accordingly appeared that the variability occasioned by such a range of pressure would be of small consequence. In the instances of both series of studies the rate of flow in grams per minute was practically a linear function of temperature and of pressure respectively.

Employing three flours: *A*, with 8.32% crude protein (13.5% moisture); *B*, with 11.60% crude protein; and *C*, with 15.50% crude protein, the rate of flow was studied in doughs made with varying proportions of water. The pressure used was 500 mm. and the temperature 30°C. The results of these tests are shown by the graph in Figure 3. The lower half records the rate of flow in grams per minute plotted against the percentage of water used. It was found that when the logarithm of the rate of flow was plotted against the percentage of water used, as recorded in the upper half of Figure 3, straight lines were obtained. Thus the relative absorption of different flours can be compared by means of these straight lines and two points accurately determined can establish them, although three points are desirable.

When dry-milk solids was added to doughs in the proportion of six grams per 100 grams of flour, the logarithmic lines of the milk doughs were parallel to those of the milk-free doughs. The distance between these parallel lines varied according to the absorption of the dry milk solids.

A farinograph was not available at the time the pressure plastometer was used, but samples of flours *A*, *B*, and *C* were stored at room temperature in hermetically sealed containers for five months, when farinograms were made. The absorption was assumed to correspond to a rate of flow of 0.7 on the logarithmic scale, which is equivalent to

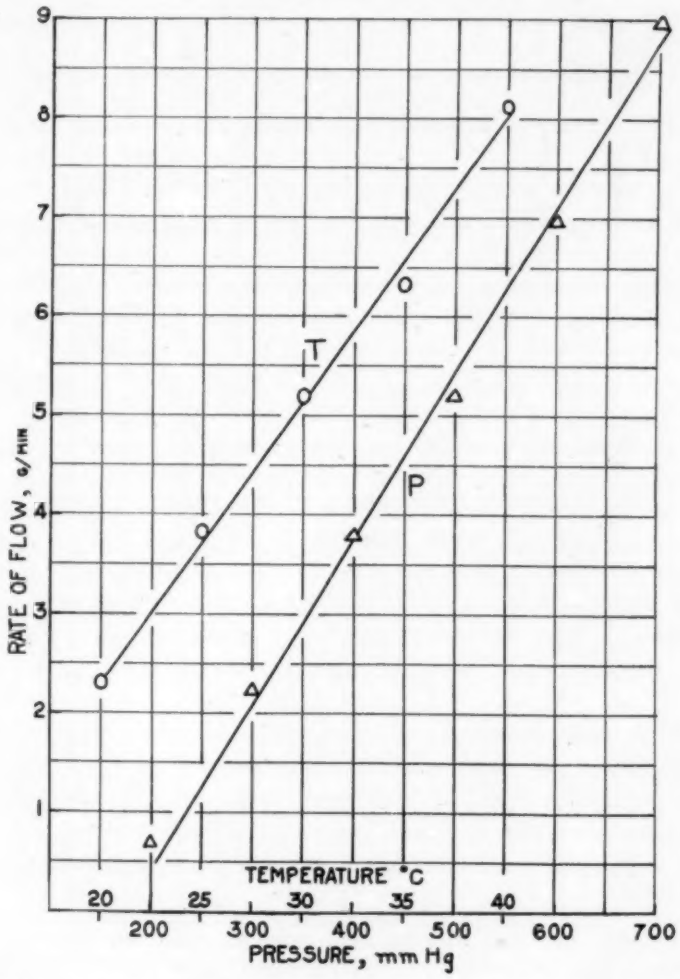

Fig. 2. Effect of temperature (*T*) and pressure (*P*) on the rate of flow of flour doughs.

5.01 g. of dough per minute. The data from the resulting farinograms are shown in Table I.

The farinograph tests indicate that the absorptions which gave the same rate of flow with the pressure plastometer resulted in different minimum mobilities as measured on the farinograph. One probable

reason for this is that a constant mixing time was employed for the doughs used in the pressure plastometer, while the minimum mobility values from the farinograph were based on the mixing time necessary to reach the minimum mobility, which was variable, as shown in Table I. No tests were carried out for this study with variable mixing times.

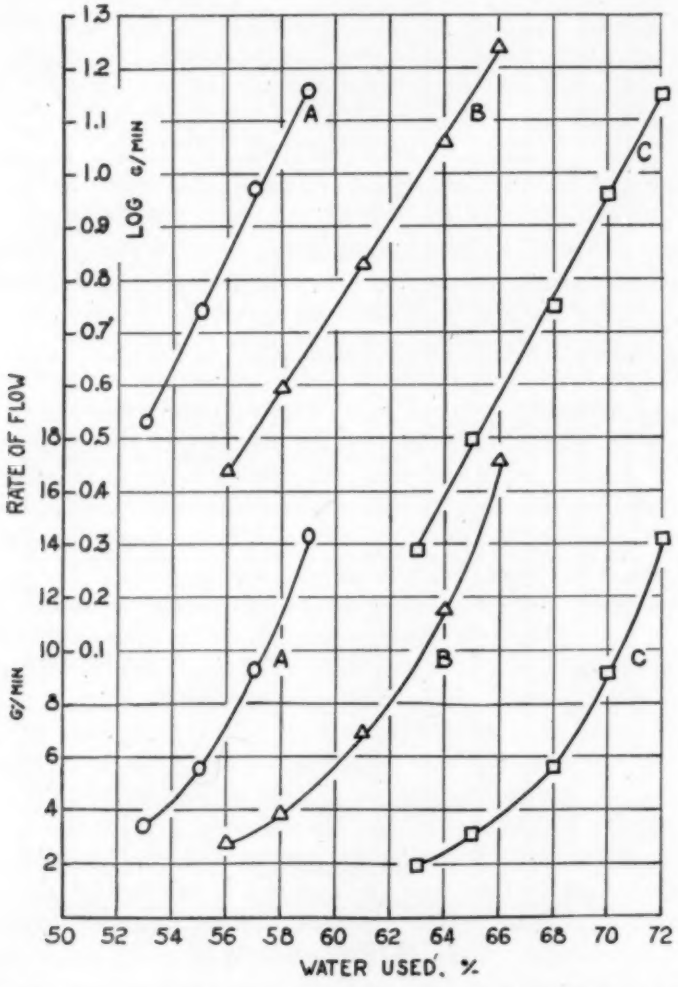

Fig. 3. Effect of proportion of water used on the rate of flow of doughs using three flours: *A*, with 8.32% protein; *B*, with 11.60% protein; and *C*, with 15.50% protein.

In using the pressure plastometer is was observed that in extruding the dough made from the soft wheat flour *A*, with 8.32% protein, the cylinder of dough retained practically the diameter of the aperture. In the case of the hard-wheat flours, *B* with 11.60% protein and *C* with

TABLE I

RESULTS OF FARINOGRAPH TESTS

Flour	Absorption	Mixing time to reach minimum mobility	Minimum mobility, in farinograph units
A	54.5	7	410
B	59.0	11	460
C	67.5	17	480

15.50% protein, the extruded dough cylinder increased in diameter as it emerged from the aperture.

Halton and Scott Blair (1936a) also observed that in extruding cylinders of dough from their dough gun, the dough cylinder swelled, "this swelling being in general greater for good than for poor quality flours." They plotted graphs showing the progressive changes in viscosity and rigidity modulus with increasing proportions of water in doughs prepared from strong and weak flours. The rigidity modulus increased at a substantial rate with increasing percentages of water in the dough. Moreover the rigidity modulus was increased more per unit of water added in the instance of a weak flour than with the strong flour. This might be interpreted to imply less sensitivity in terms of rigidity modulus in the instance of the strong flour, and hence a lesser tendency to lose the capacity to swell when the dough cylinder is extruded through an aperture. Their data also indicate that the rigidity modulus (n) of the weak flour doughs is higher at any level of viscosity (η) than the strong flour doughs and the ratio between these two physical properties, η/n, or relaxation time, may be a characteristic of flour strength.

Thus it is possible that different physical properties are affecting the rate of flow of the low-protein soft-wheat flour *A*, as compared to the higher-protein hard-wheat flours *B* and *C*. The described instrument may prove useful for the determination of relative absorptions of flours, or other dough ingredients.

Summary

A plastometer of the extrusion type was designed and constructed for use in the study of the plasticity of bread doughs. The apparatus was so constructed that doughs maintained at a constant temperature were extruded through a 6-mm. aperture from a cylinder by means of air pressure equivalent to 500 mm. of mercury. Rate of flow per minute was used as an index of the relative plasticity of the doughs. The effect of various pressures and temperatures on the rate of flow was studied, and it was found that small temperature variations may

affect the rate of flow to a greater extent than any probable variations in pressure, thus emphasizing the necessity of precise temperature control in making such measurements.

The logarithm of the rate of flow was a linear function of the proportion of water to flour used in mixing the dough.

The apparatus may be useful in studying relative absorptions of flours and other dough ingredients.

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THE PRESSUREMETER IN THE STUDY OF YEAST

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A recognized need of the cereal technologist is a convenient method of testing the uniformity and the characteristics of various commercial yeasts. Since the very wide acceptance of the pressuremeter designed by Sandstedt and Blish (1934) makes this equipment generally available, its suitability as a device for testing yeast was studied.

A method for determining the carbon dioxide produced from maltose in a liquid medium was reported by Cook and Malloch (1930). This method has the obvious disadvantage that yeast does not react the same way in a liquid medium as it does in a dough. Many methods have been devised to measure the gas given off by a dough rather than the total gas produced, which includes the gas retained and the gas evolved during fermentation. Bailey and Johnson (1924) collected the gas given off in an inverted burette. C. W. Brabender (1934) devised the fermentograph. Sullivan and Near (1935) published observations on the variability in gassing strengths of various yeasts. They found these data correlated very well with the gas produced during the proofing period of the baking test.

The work of Bohn and Favor (1938) strongly indicated that the pressuremeter has considerable merit as a means of testing yeast uniformity and provides a means of studying different yeasts. With the work of Bohn and Favor as a guide, experimental work was carried out using sucrose and maltose in straight doughs to see which sugar would show the greatest differences between various yeasts and between daily shipments of the same yeast. Following this procedure, the pressuremeter was used on regular straight-dough gassing-power determinations and with a method designed to represent the sponge dough. The data from these two methods were compared with baking-test data recorded during the time the pressuremeter records were being made.

Experimental

For all experimentation one flour, an unbleached and unmalted commercially milled flour, was used in order to eliminate flour as a variable. This also eliminated the possibility of differences in bleaching action or protease activity during the experiments.

In this type of work it is essential that there be no sugar deficiency so that the yeast activity itself will be the limiting factor in the fermentation. The amount of sugar to be used was determined by the following formula: 1000 − (gassing power × 1.33) = mg. sugar. The gassing power is the fourth-hour pressuremeter reading in mm. mercury. This is a formula suggested by R. M. Sandstedt for determining the amount of sugar to add in an experimental bake to give 10% total sugar in the dough (maltose developed in the dough during a four-hour fermentation and proof + sugar added = 10%). Ten percent total sugar insured a nearly constant excess in all bakes.

Our fourth-hour reading was 289, using the formula: 1000 − (289 × 1.33) = 0.6156 g. of sugar required. This amount of sugar was used throughout the experiments whether maltose or sucrose was used, both in the straight- and sponge-dough methods.

Preliminary work was done to determine the value of pressuremeter determinations for checking yeast uniformity. One-pound cakes of each of four popular yeasts delivered daily were used for these experiments. These four commercial yeasts will be identified as yeasts *A*, *B*, *C*, and *D*.

Table I shows typical data for the fourth-hour readings over a period of 10 days. It may be noted that yeast *D* showed a definite drop on the fourth day. Yeast *D* was baked on the third, fourth, and fifth days and the proof time lengthened 3 minutes on the fourth day. All four yeasts were very uniform in gassing strength from day to day. Baking tests showed that unless a yeast varied over 25 mm.

TABLE I

FOURTH-HOUR PRESSUREMETER READINGS OVER A PERIOD OF TEN DAYS
(0.3 g. of each of four commercial yeasts, 0.6156 g. sucrose with 10 g. flour and 10 cc. distilled water)

Yeast	Days										Range of readings
	1	2	3	4	5	6	7	8	9	10	
	Millimeters of mercury										
A	450	456	459	453	466	450	442	455	459	449	24
B	485	480	469	488	494	489	477	480	472	483	25
C	433	410	440	435	459	435	442	429	433	445	49
D	507	495	510	455	504	500	498	511	509	502	56

on a single pressuremeter determination, the difference was not noticeable in the loaf volume, but was paralleled by the proof time.

To see if maltose would show wider daily variations in the yeasts it was tried instead of sucrose. The maltose seemed to show wider differences between yeasts but not much difference in daily variations. Therefore for checking a yeast for daily uniformity either sugar could be used with good results.

The averages of ten days' gassing-power results using 0.6156 g. of sucrose, 10 g. of flour, 0.3 g. of yeast and 10 cc. of distilled water appear in Table II. From this table it is apparent that yeast *A*

TABLE II

AVERAGE OF 10 DAYS' GASSING-POWER RESULTS ON DOUGHS USING FOUR COMMERCIAL YEASTS

Hour	Yeast A		Yeast B		Yeast C		Yeast D	
	Total	Hourly	Total	Hourly	Total	Hourly	Total	Hourly
	Millimeters of mercury							
1	144	144	114	114	101	101	131	131
2	260	116	252	138	224	123	281	150
3	364	104	363	111	332	108	397	116
4	455	91	483	120	437	105	507	110
5	544	89	592	109	544	107	616	110
6	623	79	690	98	646	102	717	101
7	700	77	768	78	721	75	765	48

Formula: 0.6156 g. sucrose, 10 g. flour, 0.3 g. of each yeast, and 10 cc. distilled water.

works very fast the first hour but then slows down very decidedly. Yeast *B* reaches its peak at the second hour but does not slow down as fast as yeast *A*. Yeast *C* is slower at the start but very steady through the sixth hour of fermentation. Yeast *D* produced gas very rapidly at the start, as did yeast *A*, but did not drop off nearly as fast and was still producing well at the sixth hour. Considering the fourth hour as the critical time in straight-dough fermentation, these

data show that yeasts *B* and *D* would be producing gas at the greatest rate during the proof time, yeast *C* would be a close third, and yeast *A* would be noticeably slower.

Exactly the same procedure was followed for gassing-power studies using maltose in place of sucrose to learn if it would show greater differences between yeasts. The averages of ten days appear in Table III. Yeast *A* seemed much better able to use maltose than

TABLE III

AVERAGE OF 10 DAYS' GASSING-POWER RESULTS ON DOUGHS USING FOUR COMMERCIAL YEASTS

	Yeast A		Yeast B		Yeast C		Yeast D	
Hour	Total	Hourly	Total	Hourly	Total	Hourly	Total	Hourly
				Millimeters of mercury				
1	92	92	97	97	92	92	96	96
2	250	158	258	161	227	135	269	173
3	388	133	394	136	357	130	426	157
4	513	125	528	134	474	117	562	136
5	634	121	659	131	585	111	665	103
6	691	57	699	40	666	81	698	33
7	715	24	724	25	708	42	720	22

Formula: 0.6156 g. maltose, 10 g. flour, 0.3 g. of each yeast, and 10 cc. distilled water.

sucrose, but even with maltose yeasts *B* and *D* were producing more gas during the fourth hour than either of the other two. Yeast *C* using maltose was a poor fourth in gas production. The question then arose, which sugar was giving a true picture? To determine this, a small test bake was run which showed that using proof time as an indication of rate of gas production, both sugars were giving true pictures. When sucrose was added to the doughs, yeast *A* required the longest time to proof to height, and when maltose was used yeast *C* required the longest time to proof to height. Therefore, since sucrose is added to doughs in test baking, it was decided to use sucrose in the gassing-power tests for yeasts. However, in bakeries where malt is used it is quite possible that maltose and sucrose should be used in evaluating yeasts.

At this stage of the experiments, baking tests were run with both the straight-dough and the sponge-dough method, in both cases with sucrose in the formula. For the baking tests, however, bleached flour was used which had been milled at exactly the same time on the same mill as the flour used for the pressuremeter determinations, but which had been taken off the mill after instead of before the bleach. Preliminary baking tests showed a correlation between yeast activity and proofing time. Further investigation showed that variations between

yeasts also affect the characteristics of the finished loaf. The doughs [1] were mixed two minutes on the G-R Swanson dough mixer, scaled into two equal doughs, and placed in the fermentation cabinet at 86°F. for three hours. This temperature was the same as that of the water bath used in all pressuremeter determinations. The doughs were machine-punched twice, machined for panning, proofed to height and baked for 30 minutes in a rotary hearth oven at 425°F. The Thompson Model G Roll Moulder was used for all punches and for pan molding. The average proof time for seven days' baking (not in sequence) appears in Table IV. The pressuremeter indicated these results except for a slightly larger difference between yeasts *B* and *D*. It should be noted that yeast *A* was the last to proof to height each day of the bake and yeast *C* was next to last in proofing to height all but two days.

TABLE IV

DAILY PROOF TIME OF DOUGHS USING FOUR COMMERCIAL YEASTS

First in proofing to height	Second in proofing to height	Third in proofing to height	Fourth in proofing to height
Yeast *C* 44½ min.	Yeast *D* 45 min.	Yeast *B* 48 min.	Yeast *A* 50½ min.
C 49½	*B* 51	*D* 54	*A* 58
D 46	*B* 47	*C* 48	*A* 50½
D 49	*B* 49½	*C* 50	*A* 53½
D 52	*B* 53	*C* 54	*A* 58
B 50½	*D* 53	*C* 53½	*A* 57
B 52½	*D* 53½	*C* 55	*A* 57

Average proof time for the seven-day bake: yeast *B* 50.2 min., yeast *D* 50.3 min., yeast *C* 51 min., and yeast *A* 55 min.

The loaves were scored for inside and outside characteristics and were evaluated by giving to the duplicates showing the best development a grade of 1, the next best 2, etc. The result of this composite

TABLE V

COMPOSITE INTERIOR AND EXTERIOR EVALUATIONS OF THE DUPLICATE LOAVES USING FOUR COMMERCIAL YEASTS

	Days						
	1	2	3	4	5	6	7
	Yeasts						
The yeast rating *first* on loaf characteristics	*B*	*D*	*D*	*C*	*A*	*A*	*B*
Yeast rating *second*	*D*	*C*	*B*	*B*	*B*	*B*	*D*
Yeast rating *third*	*C*	*B*	*C*	*D*	*C*	*D*	*C*
Yeast rating *fourth*	*A*	*A*	*A*	*A*	*D*	*C*	*A*

scoring on the seven days' bake appears in Table V. Giving 3 points to the yeast rating 1, 2 points to the yeast rating 2, and 1 point to the yeast rating 3 for each bake, we find the value of yeast *A* to

[1] Formula: 200 g. flour (15% moisture basis, undiastated), 12 g. sugar, 3½ g. salt, 6 g. yeast, 4 g. liquid shortening.

be 6, yeast *B* 15, yeast *C* 9, and yeast *D* 12. Here again is a correlation with the rate of gas production, for the pressuremeter showed yeast *B* as producing most gas during the fourth hour, yeast *D* second largest production, yeast *C* next, and yeast *A* producing the least. It should be noted that rate of gas production is here correlated with texture and crust characteristics, possibly because of the proper development of the dough under this set of conditions.

TABLE VI

VOLUMES OBTAINED DURING SEVEN DAYS' BAKES USING FOUR COMMERCIAL YEASTS

Yeast *D* 685 cc.	Yeast *B* 683 cc.	Yeast *C* 675 cc.	Yeast *A* 660 cc.
A 670	*C* 660	*B* 657	*D* 653
D 680	*B* 675	*A* 665	*C* 655
C 675	*B* 665	*D* 660	*A* 645
D 670	*A* 668	*C* 662	*B* 645
B 690	*D* 685	*C* 680	*A* 663
D 675	*B* 670	*C* 660	*A* 653

The loaf volumes for the seven bakes appear in Table VI. Applying the same system of evaluation, the volume scores, yeast *A* rates 6 points, yeast *B* 12, yeast *C* 9, and yeast *D* 12. Note that the rate of gas production the fourth hour does have a definite effect on the loaf volumes. Yeast *D*, which was producing gas at the greatest rate during the fourth hour, had the largest loaf volume 4 out of 7 days' bakes, yeast *B*, which produced gas next in line, was second in loaf volume 4 out of 7 days' bakes, yeast *C* was third 4 out of 7 and yeast *A* was last 4 out of 7.

TABLE VII

COMBINED DATA OF PRESSUREMETER, PROOF TIME, LOAF VOLUME AND COMPOSITE SCORE IN THE STRAIGHT-DOUGH PROCEDURE

Yeast	Average fourth-hour gas production [1]	Average proof time [2]	Average loaf volume	Average composite score
	mm.	*min.*	*cc.*	
A	91	55	660.5	Fourth place
B	120	50.2	669	First place
C	105	51	666.7	Third place
D	110	50.3	672.5	Second place

[1] The gassing-power data are a ten-day average.
[2] The baking data are a seven-day average.

Table VII is presented to show the pressuremeter data and the baking data in a composite picture. Here we find that the fourth-hour gas production in the pressuremeter gave a good picture of what the four yeasts would do in straight-dough baking. It should be noted that the baking was alternated between the two authors who kept

their own data until all seven bakes were finished. It should also be noted that the texture and loaf characteristics were very difficult to differentiate, but even under this handicap, the final results checked well with the proof time and volume scores.

TABLE VIII

AVERAGE OF 10 DAYS' GASSING-POWER RESULTS ADDING SUCROSE THE FIFTH HOUR[1]

Yeast *A*		Yeast *B*		Yeast *C*		Yeast *D*	
Total	Hourly	Total	Hourly	Total	Hourly	Total	Hourly
Millimeters of mercury							
107	107	90	90	87	87	102	102
255	148	247	157	224	137	272	170
361	106	361	114	336	112	371	99
403	42	399	38	386	50	407	36
425	22	422	23	413	27	431	24
PRESSUREMETER OPENED AND 0.6156 G. OF SUCROSE STIRRED IN							
141	141	136	136	130	130	140	140
259	118	259	123	242	112	266	126
380	121	372	113	345	103	377	111

[1] Ten g. flour, 0.3 g. of each yeast, and 10 cc. distilled water to start pressuremeter. At fifth hour 0.6156 g. sucrose was stirred in and the pressuremeter returned to water bath.

TABLE IX

AVERAGE OF 10 DAYS' GASSING-POWER RESULTS ADDING MALTOSE THE FIFTH HOUR[1]

Yeast *A*		Yeast *B*		Yeast *C*		Yeast *D*	
Total	Hourly	Total	Hourly	Total	Hourly	Total	Hourly
Millimeters of mercury							
103	103	90	90	86	86	111	111
250	147	240	150	221	135	269	158
361	111	358	118	338	117	361	92
396	35	396	38	392	54	400	39
420	24	419	23	417	25	428	28
PRESSUREMETER OPENED AND 0.6156 G. OF MALTOSE STIRRED IN							
127	127	138	138	125	125	147	147
234	107	256	118	215	90	273	126
329	95	355	99	288	73	375	102

[1] Ten g. flour, 0.3 g. of each yeast, and 10 cc. distilled water to start pressuremeter. At fifth hour 0.6156 g. maltose was stirred in and the pressuremeter returned to water bath.

The foregoing procedure was also followed with maltose instead of sucrose at the fifth hour. Average results for 10 days with maltose appear in Table IX. Here again, as in the straight-dough determinations, yeast *A* did not seem to handle maltose quite as well the first hour, and yeast *C* showed the best ability to utilize both sugars. A difference occurred here, in that yeast *D* showed ability to utilize maltose the first hour it was added in the sponge procedure, whereas

this same yeast did not show this utilization when maltose was used in the straight-dough procedure. This may be due to the fact that the induction period for the fermentation of maltose was covered by the sponge fermentation. No particular advantage in using maltose was apparent from these experiments and, since sucrose is used in doughs at this stage in baking, it seems advisable to use sucrose in the evaluation of yeasts. It should be noted, however, that when checking for daily variations in shipments of yeasts, yeasts *A* and *B* showed much wider variations when maltose was used.

Sponge Pressuremeter Values and Bakes

In running pressuremeter determinations on the yeasts using the sponge method, the same temperature was used in the water bath as was used for the straight doughs (86°F.). The pressuremeter was started with 10 g. of the same flour used for the straight-dough tests, 0.3 g. of each yeast, and 10 cc. distilled water. The pressuremeter was read each hour. At the end of the fifth hour it was removed from the water bath, the lid removed and 0.6156 g. of sucrose stirred in, the lid replaced, and the pressuremeter returned to the water bath. The averages for a 10 day run by this sponge method appear in Table VIII. These data show that yeast *A* and yeast *D* pick up rapidly after the sugar is added, yeast *B* and yeast *C* are slower the first hour after which yeast *B* steps up with yeasts *A* and *D*. Since the critical time for sponge doughs is usually the first hour after the sugar is added, yeasts *A* and *D* should be superior for sponge doughs since they are producing gas at a more rapid rate during this critical time. Yeasts *C* and *D* showed wider daily variations when sucrose was used. Therefore, in checking yeasts for uniformity a technician should try out both sugars over a period of time to learn which will give him the most useful information.

A method of baking a sponge was patterned after the work of Shellenberger and Ziemke (1939). Total weight of flour was 200 g. on a 15% moisture basis. Both the sponge and dough were mixed two minutes in the Swanson G-R mixer. The dough was fermented 20 minutes, divided into two equal portions, rounded up, allowed to rest 15 minutes, panned, proofed to height and baked in the usual manner (425°F.).

Sponge	
Flour	140 g. (undiastated)
Yeast	6 g.
Sugar	6 g.
Shortening	4 cc. (liquid)
Water to proper consistency	

Sponge time, 5 hours

Dough	
Flour	60 g.
Sugar	6 g.
Salt	3½ g.
Water to proper consistency	

Exactly the same ingredients were used in the sponge doughs as were used in the straight doughs and the doughs were fermented in the same cabinet at 86°F. This was done with the sponge because no attempt had been made to adjust the water-bath temperature of the sponge pressuremeter determinations. It should be noted that had the temperature of the sponge been lowered to a point more in line with common bake-shop practice, different evaluations of the yeasts might have occurred. This statement is made because, on one set of bakes not included in this report, the fermentation cabinet thermostat stuck and the temperature had been only 79°F. during the sponge fermentation. This bake was continued and the cabinet temperature raised during the mixing, fermentation, rest, and pan proof. Yeast *C*, usually slow proofing, was faster under these conditions and moved up to second place in rate of proof at this lower temperature. When the doughs were ready for the oven, the cabinet temperature had risen to about 84°F.

TABLE X

DAILY PROOF TIME OF THE FOUR COMMERCIAL YEASTS USING THE SPONGE PROCEDURE [1]

First to the oven	Second to the oven	Third to the oven	Fourth to the oven
Yeast *D* 34½ min.	Yeast *A* 39½ min.	Yeast *B* 40½ min.	Yeast *C* 41 min.
A 36	*D* 36½	*B* 39½	*C* 45
A 38	*B* 39	*D* 40	*C* 43½
D 41	*A* 42	*B* 43½	*C* 44½
B 44½	*A* 46	*D* 46½	*C* 49
A 40½	*D* 41	*B* 42½	*C* 48½
A 42	*D* 43	*B* 45	*C* 46

[1] Averages: yeast *D* 40.2 min., yeast *A* 40.5 min., yeast *B* 42.3 min., yeast *C* 45.3 min.

The averages for seven days' baking for proof time (proofing to height) appear in Table X. Yeasts *A* and *D* proofed up according to the pressuremeter determinations (gas produced the first hour after sugar added). Yeasts *C* and *D* showed the widest range of proofing time over the seven-day bake period. Even this was in line with the pressuremeter, for yeasts *C* and *D* showed the widest daily variation when sucrose was used. In bake-shop conditions where both sugars are available, perhaps this difference would level off, for yeasts *A* and *B* showed wider variations when maltose alone was used in the pressuremeter determinations.

Table XI shows the composite score of the interior and exterior of the loaves. In order to eliminate any tendency to depend on the pressuremeter results in evaluation, one technician baked and numbered the loaves in code, while the other technician graded the pairs.

TABLE XI

COMPOSITE INTERIOR AND EXTERIOR EVALUATION OF DUPLICATE LOAVES USING FOUR COMMERCIAL YEASTS IN THE SPONGE BAKING PROCEDURE—SEVEN DAYS

First in loaf quality	Second in loaf quality	Third in loaf quality	Fourth in loaf quality
Yeast *A*	Yeast *D*	Yeast *C*	Yeast *B*
A	*B*	*D*	*C*
A	*B*	*D*	*C*
D	*A*	*B*	*C*
A	*B*	*C*	*D*
A	*D*	*B*	*C*
B	*A*	*C*	*D*

Here again the technicians alternated in baking and in grading. Yeast *A* was graded first consistently. Yeast *D*, however, did not stay in line with the pressuremeter, for yeast *B* excelled yeast *D* in loaf quality. Yeast *C* was last as indicated by the pressuremeter. The fact that yeasts *B* and *D* changed places here may be due to differences in the way the two yeasts affect the gas-retention properties of the dough.

TABLE XII

VOLUMES OBTAINED DURING THE SEVEN DAYS' BAKE USING FOUR COMMERCIAL YEASTS IN THE SPONGE BAKING PROCEDURE [1]

First in volume	Second in volume	Third in volume	Fourth in volume
Yeast *D* 800 cc.	Yeast *A* 740 cc.	Yeast *B* 735 cc.	Yeast *C* 705 cc.
B 700	*A* 695	*D* 690	*C* 680
A 720	*B* 710	*D* 698	*C* 688
B 705	*A* 690	*D* 680	*C* 600
A 720	*D* 705	*C* 700	*B* 670
A 695	*D* 690	*B* 685	*C* 625
D 700	*A* 690	*B* 680	*C* 650

[1] Average loaf volume: yeast *D* 707.5 cc., yeast *A* 707 cc., yeast *B* 695 cc., and yeast *C* 664 cc.

In Table XII appear the volume scores of the loaves in the seven bakes. It may be observed that yeast *D* has the highest loaf volume of any of the yeasts and yeast *B* is third in volume. Using the 3–2–1

TABLE XIII

COMBINED DATA OF PRESSUREMETER, PROOF-TIME, LOAF-VOLUME, AND COMPOSITE SCORE—SPONGE-DOUGH PROCEDURE

Yeast	Average sixth-hour gas production	Average proof time	Average loaf volume	Average composite score
A	141 mm.	40.5 min.	707 cc.	First
B	136	42.3	695	Second
C	130	45.3	664	Fourth
D	140	40.2	707½	Third

system in scoring, we find that yeasts *A* and *D* have exactly the same score on volume.

Table XIII combines all these data on the sponge pressuremeter and sponge baking. The millimeters of pressure in the pressuremeter the first hour after the sugar is introduced are a very good indication of how that yeast will behave in a sponge baking procedure.

Summary and Conclusions

The pressuremeter was used on an unmalted flour to determine the characteristics and uniformity of various commercial yeasts. The data obtained with the pressuremeter under various conditions correlated very well with data obtained by actual test baking both on straight-dough and sponge methods. The pressuremeter shows very slight variations in daily shipments of yeast that cannot be found in the bake and for this reason slight daily variations could well be discounted. The pressuremeter shows very marked differences between various commercial yeasts, and by proper manipulation it will show certain yeasts more adaptable to certain conditions. If the conditions under which a yeast is to be used are known, the pressuremeter will assist in determining yeast characteristics that will best be suited to this set of conditions.

The pressuremeter equipment of Sandstedt and Blish has a definite place in the cereal laboratory for testing yeast uniformity and character. It will differentiate yeasts in a manner that will in most cases be correlated with the baking test.

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EFFECT OF STORAGE TEMPERATURES UPON THE VIABILITY AND BAKING PROPERTIES OF COMPRESSED YEAST

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(Read at the Annual Meeting, May 1939)

It is not always possible to have freshly produced compressed yeast delivered to the bakery daily. Hence it becomes necessary to store the yeast for a short or perhaps even a long period of time before use. The question then arises as to what temperature should be selected for storing the yeast. Should the yeast be frozen? If so, what procedure should be employed in getting the yeast in condition for baking?

Cook and Malloch (1930) state that yeast stored at about 32°F. up to ten days of time lost very little in gas production. Harrel (1926) stored yeast at 50°, 80°, 90°, and 100°F. and at the end of 24 hours he determined gas strength and made baking tests. His results showed that with yeasts stored for the same length of time there was a steady decrease in the gas-producing power, as the temperature was increased. Staiger and Glaubitz (1929) on the other hand stored yeast at low temperatures, even below freezing. They found that yeast which was frozen at from +14°F. to −13°F. for one to four days and subsequently thawed at room temperature and at 41°F. respectively, showed but little change in properties. The baking and keeping qualities of the yeast as well as the nitrogen content and biological appearance were almost normal.

Iwanowski and Brezezinski (1934) studied the effect of time upon yeast stored at different temperatures. They found that yeast could be stored at 32°F. for two to three months without marked deterioration and at 56°F. for about two weeks, after which time the yeast would have about 10% to 20% dead cells; and that after storage at 72°F. for one week it would have approximately 20% of dead cells. Their conclusion was that the yeast could be stored at these temperatures and for these periods of time without marked changes in its physiological state, except ability to bud, and without losing commercial value.

Weaver, Talbott, and Coleman (1933) in testing yeast variability studied two brands of yeasts. Their test consisted of baking 50 replicate loaves using each brand of yeast and taking the mean loaf volume as a criterion of change. They held the yeast at room temperature for

[1] Bureau of Chemistry and Soils.
[2] Food and Drug Administration.

seven hours on each baking day and at an electrical refrigerator temperature the rest of the time. Baking tests were made with the fresh yeast six hours old and again after 24, 48, 96, and 168 hours; their results showed that with one of the brands of yeast there was practically no change up to 96 hours and with the other one none even up to 168 hours.

In order to gather further information on this storage problem, a study was made as detailed herewith. Five pounds of compressed yeast packed in crumpled newspapers and placed in a pasteboard carton along with dry ice were transported by airplane across the continent from the Pacific coast. The yeast was quite cold but not frozen at the time of arrival. Baking tests were made immediately with this yeast in comparison with fresh, unfrozen yeast of another brand, after which one-pound cakes of both brands of yeast were placed in storage at 0°, 20°, 30°, and 45°F. At the end of one month, two months, and three months, respectively, portions of the cakes of yeasts were removed from storage and tested for plate counts of yeast cells, percentage of dead cells, pH determinations, and baking quality. Two methods were used in thawing the yeast preparatory to baking. In one method the frozen yeast was suspended in 50 cc. of ice water and placed at once into the dough mix, with the balance of the water warm enough to yield a dough of proper temperature; in the other method the yeast was removed from the freezing room to a 50°F. room, allowed to thaw overnight, and then used in the usual manner. This same procedure was used throughout all the tests.

The first test was made upon receipt of samples.

TABLE I

COMPARISON OF FRESH YEAST WITH YEAST TRANSPORTED ACROSS THE CONTINENT BY AIRPLANE WITH DRY-ICE REFRIGERATION

	Yeast *A*, transported sample	Yeast *B*, fresh sample
Plate count (*million cells per g.*)	1,020	3,000
Dead cells, %	2	1
pH of yeast	5.5	5.6
Loaf volume, *cc.*	2,290	2,250

The transported-sample yeast (*A*) was somewhat more yellow in color than the fresh-sample yeast (*B*). Yeast *A* was slightly soft and sticky when received. It made a very good loaf of bread, almost the same kind of loaf as did yeast *B*.

The odd-numbered loaves (Figure 1) were made with yeast *B* and the even-numbered loaves with yeast *A*, with one exception. The loaves

TABLE II

RESULTS OF TESTS MADE WITH THE YEASTS AFTER ONE MONTH'S STORAGE

	0° F.—Yeast		20° F.—Yeast		30° F.—Yeast		45° F.—Yeast		0° F.–20° F.
	B	*A*	*B*	*A*	*B*	*A*	*B*	*A*	Yeast *A*
THAWED IN ICE WATER									
No. in figure	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*15*
Cell count (*million per g.*)	4,300	820	1,560	1,050	4,800	2,400	7,920	1,440	130
Dead cells, %	0	20	4	16	0	4	0	10	8
pH of yeast	5.2	5.9	4.7	5.5	4.7	6.9	6.7	7.6	5.4
Loaf vol., *cc.*[1]	1,950	1,790	2,200	2,075	2,300	2,200	2,030	1,875	21″×11¾″
Loaf character	Good	Poor	Very good	Fair	Very good	Very good	Good	Fair	Poor
THAWED OVERNIGHT BEFORE USING									
No. in figure	*9*	*10*	*11*	*12*	*13*	*14*			*16*
Cell count (*million per g.*)	4,400	1,600	6,000	1,680	4,320	2,100	—	—	410
Dead cells, %	4	16	0	6	0	0	—	—	30
pH of yeast	5.3	5.6	5.3	5.6	4.9	6.8	—	—	5.6
Loaf vol., *cc.*	2,100	1,800	2,075	2,050	2,180	2,000	—	—	20½″×12″
Loaf character	Good	Poor	Good	Good	Good	Good	—	—	Poor

[1] When the loaf was too small to measure in the loaf-volume apparatus the longitudinal and transverse circumferences, in inches, were measured.

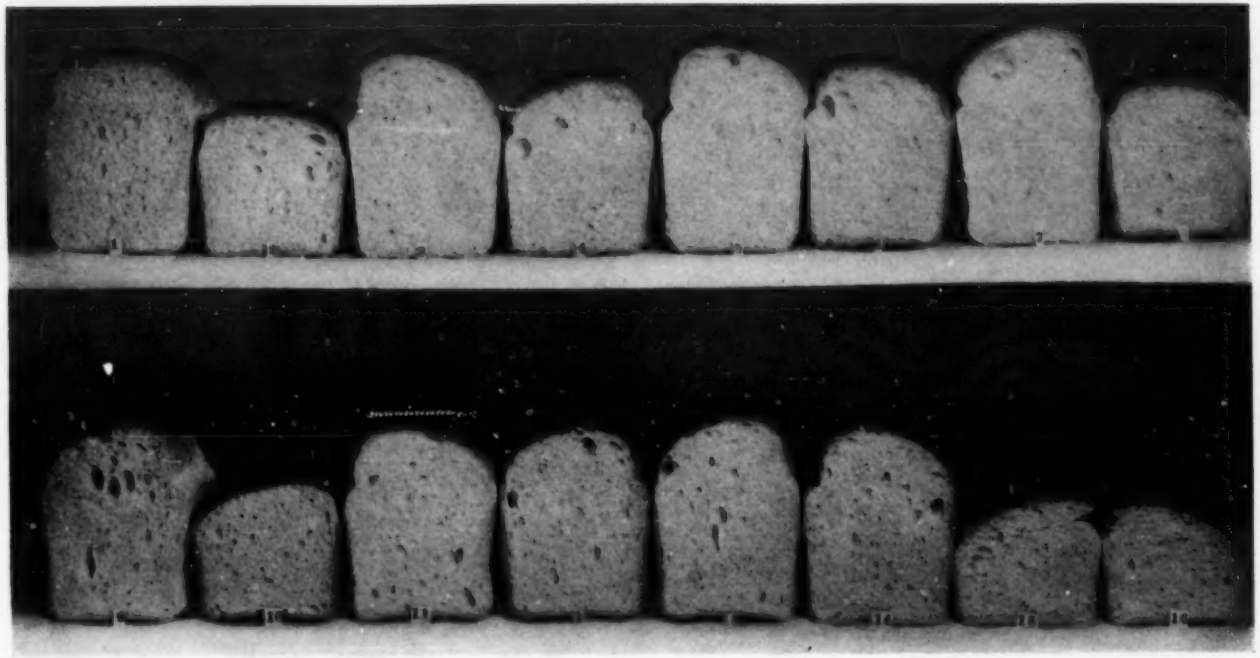

Fig. 1. One month's storage of yeast. *A*, transported yeast packed in dry ice; *B*, fresh yeast.

Loaf No.	Yeast	Storage temp., °F.	
1	*B*	0	
2	*A*	0	
3	*B*	20	
4	*A*	20	Suspended in ice water,
5	*B*	30	used at once.
6	*A*	30	
7	*B*	45	
8	*A*	45	

Loaf No.	Yeast	Storage temp., °F.	
9	*B*	0	
10	*A*	0	
11	*B*	20	Thawed at 50° F. overnight, then used.
12	*A*	20	
13	*B*	30	
14	*A*	30	
15	*A*	0	For 6 days, then at 20° F. 27 days, then used.
16	*A*	0	For 6 days, then at 20° F. 27 days, thawed overnight.

on the top row were made by suspending the frozen yeast in ice water and then incorporating it in the doughs immediately, while the corresponding six loaves on the left of the picture in the bottom row were made from yeast that had thawed overnight at 50°F. and then was incorporated in the doughs.

The first pair of loaves toward the left on both top and bottom rows were made with yeast stored at 0°F., the second pair with yeast stored at 20°F., the third at 30°F., and the last pair on the top row were made from yeast stored at 45°F. On the bottom row the last two loaves to the right were made with yeast *A*, which had been stored at 0°F. for 6 days and then at 20°F. for 27 days. Loaf *15* was made with frozen yeast suspended in ice water and used at once, while for loaf *16* the yeast was thawed overnight in the 50°F. room and then used. This cake of yeast *A* had greatly deteriorated by the end of the first month's storage.

As shown in Figure 1, there had been some deterioration of the yeast *A* after one month's storage. This was especially noticeable where the yeast had been stored at 0°F. and at 45°F. and also with the yeast that at first was stored at 0° for six days and then transferred to 20°F. for 27 days (*15* and *16* in Figure 1).

After two months' storage the deterioration was still more pronounced (as shown in Figure 2). By this time there were no satisfactory loaves made from yeast *A* stored at any of the different temperatures. Yeast *B* still made quite good loaves, when stored at all four temperatures. Yeast *B* had not been packed with dry ice; hence it had not been subjected to such extreme cold as had yeast *A*.

After three months' storage, the deterioration of the yeast was still more pronounced (as shown in Fig. 3). At this time none of the loaves was entirely satisfactory. Even though some of the loaves made with yeast *B* had good external appearance, the crumb was inferior. The grain was coarse and texture firm. All the loaves made from yeast *A* were quite unsatisfactory.

The yeasts stored at 0°F. did not make quite as good loaves as those stored at 20° or 30°F. At 45°F. the yeast darkened in color and crumbled badly. This yeast did not keep as well as that stored at 20° or 30°F., but when not previously frozen produced satisfactory results up to the end of two months' storage.

All of the yeast being tested had incorporated with it some starch, and upon freezing these starch cells ruptured and the result was that when the frozen yeast was thawed it softened down into a pasty mass. This made the process of handling more difficult.

At 30°F. the yeast did not freeze and hence did not lose its normal physical condition, and yet it continued to produce just as satisfactory bread as yeast stored at any other temperature.

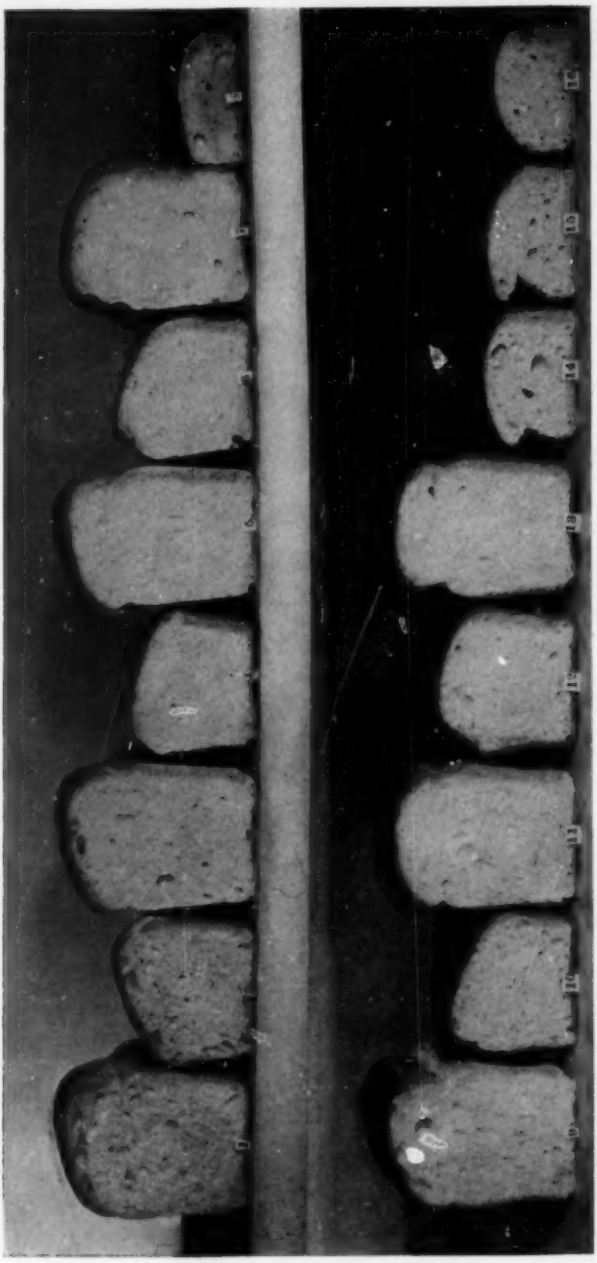

Fig. 2. After two months' storage of yeast. (Loaves correspond to those in Fig. 1, with the exception that loaves *15* and *16* were stored at 20° F. for 56 days.)

TABLE III

RESULTS OF TESTS MADE WITH THE YEASTS AFTER TWO MONTHS' STORAGE

	0° F.—Yeast		20° F.—Yeast		30° F.—Yeast		45° F.—Yeast		0° F.–20° F.
	B	*A*	*B*	*A*	*B*	*A*	*B*	*A*	Yeast *A*
THAWED IN ICE WATER									
No. in figure	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*15*
Cell count (*million per g.*)	9,000	1,080	2,700	750	2,000	240	5,600	Less than 1	960
Dead cells, %	7	20	3	30	0	2	1	85	85
pH of yeast	4.8	5.4	4.7	5.0	5.5	7.3	7.8	7.8	5.2
Loaf vol.[1]	2,230	21″×12″	2,275	22″×12½″	2,300	21½″×12½″	2,150	19¼″×6″	19¼″×10½″
Loaf character	Good	Small, poor	Good	Fair	Very good	Small, poor	Good	Very small, very poor	Small, poor
THAWED OVERNIGHT BEFORE USING									
No. in figure	*9*	*10*	*11*	*12*	*13*	*14*	—	—	*16*
Cell count (*million per g.*)	210	960	2,100	760	3,200	1,160	—	—	300
Dead cells, %	8	36	6	9	0	7	—	—	90
pH of yeast	5.4	5.6	4.9	5.5	5.8	7.3	—	—	5.4
Loaf vol.	2,230	21⅜″×12″	2,125	23″×13″	2,275	19½″×10⅜″	—	—	19½″×9¼″
Loaf character	Very good	Small, poor	Good	Fair	Very good	Small, very poor	—	—	Small, poor

[1] See footnote 1, Table II.

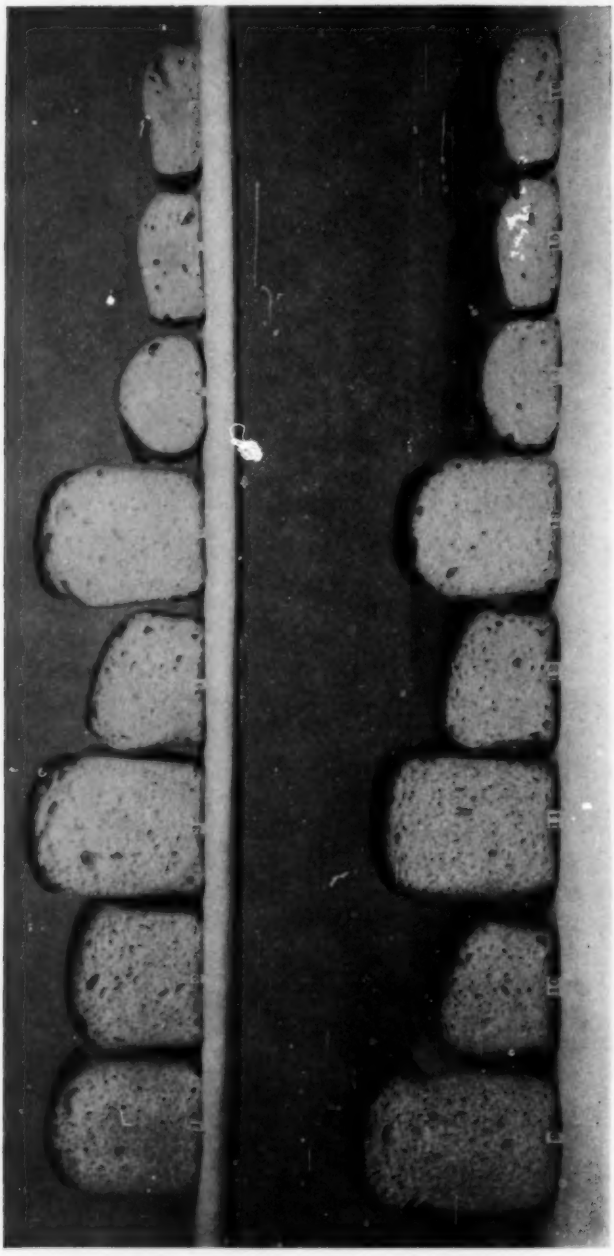

Fig. 3. After three months' storage of yeast. (Loaves correspond to those in Figs. 1 and 2, with the exception the *15* and *16* were stored at 20° F. for 89 days.)

TABLE IV

RESULTS OF TESTS MADE WITH YEASTS AFTER THREE MONTHS' STORAGE

	0° F.—Yeast		20° F.—Yeast		30° F.—Yeast		45° F.—Yeast		0° F.–20° F.
	B	*A*	*B*	*A*	*B*	*A*	*B*	*A*	Yeast *A*
THAWED IN ICE WATER									
No. in figure	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*15*
Cell count (*million per g.*)	120,000	3,100	9,700	2,400	3,700	160	20	7/100	120
Dead cells, %	15	15	11	45	0	25	80	95	90
pH of yeast	4.7	5.4	4.4	5.1	5.9	7.3	7.8	7.0	5.4
Loaf vol.[1]	24″×13⅜″	23¼″×13¼″	25″×15½″	20⅞″×11⅞″	24½″×14½″	19½″×9″	18½″×8⅞″	18⅞″×8¾″	19¼″×8⅞″
	1,875	1,750	2,150	—	2,025	—	—	—	—
Loaf character	Fair	Poor	Good	Poor	Good	Very poor	Very poor	Very poor	Very poor
THAWED OVERNIGHT BEFORE USING									
No. in figure	*9*	*10*	*11*	*12*	*13*	*14*	—	—	*16*
Cell count (*million per g.*)	4,500	2,000	6,300	2,600	10,800	320	—	—	1,600
Dead cells, %	16	35	12	32	1	3.4	—	—	96
pH of yeast	5.4	5.6	4.3	5.2	6.6	7.2	—	—	5.5
Loaf vol.	26¼″×16¼″	21¼″×11⅞″	25″×15⅝″	21⅛″×11⅞″	23¾″×13¾″	19½″×9¼″			19″×8⅜″
	2,500	—	2,170	—	1,850	—	—	—	—
Loaf character	Good	Very poor	Medium	Very poor	Fair	Very poor	—	—	Very poor

[1] See footnote 1, Table II.

While frozen yeast can be suspended in ice water and used immediately, the balance of the water must be sufficiently warm to offset this low temperature so that normal fermentation can proceed; consequently preference is given to the method of allowing the yeast to thaw slowly at approximately 50°F. overnight, and then incorporating it in the dough in the usual manner.

Since yeast *A* made very good bread when it was first received but deteriorated more rapidly upon storage than did yeast *B*, it was thought that perhaps the low temperature to which yeast *A* had been subjected when it was packed in dry ice for shipment might have been the cause of the more rapid deterioration. In order to test this possibility, two one-pound packages of yeast were obtained. One of them was surrounded with crumpled paper in a pasteboard carton and dry ice placed in the container over the cake of yeast. Upon examination the following day, it was observed that the dry ice had evaporated and more was added. At the end of 48 hours the carton was placed in a room at 20°F. and kept at that temperature for one month.

The second cake of yeast was handled in the same manner except that it was placed in a vacuum-walled jar similar to a large thermos bottle, with the dry ice immediately surrounding the wrapper on the cake of yeast. After two days of this treatment the yeast was transferred to a pasteboard carton and placed in a room at 0°F. for one month.

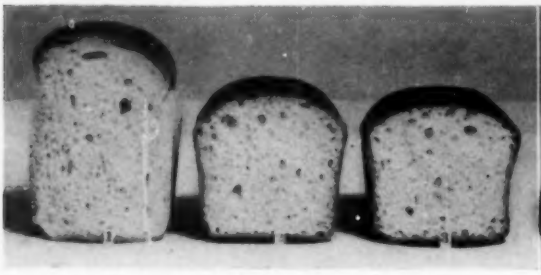

Fig. 4. Comparison of fresh and frozen yeast.

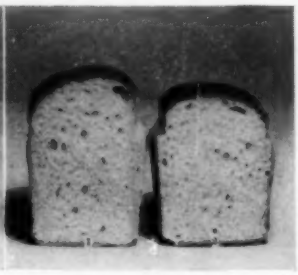

Fig. 5. Comparison of fresh yeast with yeast frozen at − 109° F. for 24 hours

After the month's storage these two yeasts were compared with fresh yeast in making bread. The result is shown in Figure 4. It will be seen that great injury had been done to the yeast. Loaf *2* was made with the yeast that was packed in the pasteboard carton along with the dry ice and subsequently stored at 20°F. This treatment was intended to simulate that given yeast *A*.

Loaf *3* was made with the yeast that had been given the more severe treatment, but the loaf was only slightly inferior to loaf *2*.

The microscopical examination of these yeasts showed both by cell count and percentage of dead cells that one month's storage after sharp freezing for two days was detrimental to the yeast and that a temperature of 0°F. was more harmful than 20°F.

In order to determine what proportion of this damage was due to subjecting the yeast to the low temperature and what proportion to the storage period, another sample of yeast was placed in the vacuum-walled jar with a goodly portion of dry ice and the temperature surrounding the yeast was determined to be that of evaporating dry ice, −109°F. After 24 hours at that temperature the yeast was transferred to an electrical refrigerator for another 24 hours; it was then used in baking in comparison with fresh yeast that had not been subjected to a low temperature. The result may be seen in Figure 5. While the external appearance of this loaf *2* was almost as good as that of loaf *1* made with the fresh yeast, the internal characteristics were not nearly so good. The grain was coarse, with thick cell walls, the texture was more firm, and the color was slightly darker. The crust color also showed more caramelization. It is interesting to note that a living organism like yeast can withstand such extremely low temperature for 24 hours and later resume biological activity. These latter tests indicate that some damage is done the yeast when it freezes and that this damage is more pronounced as the subsequent storage period is prolonged.

Summary

Compressed yeast packed with dry ice for a short period (two days) was stored along with fresh compressed yeast at 0°, 20°, 30°, and 45°F. for three months. Microscopical, pH, and baking tests were made at the beginning and at the end of one month's, two months', and three months' storage, respectively, at the temperatures indicated above.

The yeast that had been packed with dry ice deteriorated more rapidly than the fresh yeast stored for the same length of time and at the same temperatures. The frozen yeast became mushy after it was thawed, making it more difficult to handle.

Of the different storage temperatures used, 30°F. is considered the most suitable since the yeast did not freeze at that temperature, nor lose its normal consistency, and bread made from this yeast was fully equal to that made with yeast stored at any other temperature.

The temperature of evaporating dry ice (−109°F.) injures yeast in 24 hours and subsequent storage below freezing increases the amount of deterioration.

The general conclusion to be drawn as a result of this investigation is that approximately 30°F. is the most suitable temperature for the storage of compressed yeast.

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LABORATORY MALTING. III. STEEPING EQUIPMENT AND METHOD[1]

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(Read at the Annual Meeting, May 1939)

The first paper in this series described equipment for making batches of malts in the laboratory under reproducible conditions and on a routine scale. The germinators and kilns have proved reasonably satisfactory but the steep tank required modification. After considerable experimentation steeping equipment of an entirely different type was designed and constructed. It has now been in operation for some time and since it has proved generally satisfactory and contains certain advantageous automatic features, it appeared worth while to publish a description of it.

It is the practice in our laboratories, as in the Malting Laboratory at the University of Wisconsin (Dickson, Shands, Dickson, and Burkhart, 1935), to steep all samples to the same moisture content. Owing to differences in kernel size and certain varietal effects (cf. Meredith and Anderson, 1938) samples differ considerably in the time they take to reach the desired moisture content, 44% in our laboratories. The time required by each sample is determined in practice by means of pilot steeping experiments which can readily be carried out under routine conditions.

In making a batch of malts all samples must be removed from the steep at the same time. Thus, since they may require different lengths of steep, it will be obvious that they may have to be put into the steep at different times. In order to have a fully automatic steep tank, it is

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therefore necessary to arrange not only for automatic changing of water and automatic aeration, but also for an automatic method for starting the steeping of each individual sample at any predetermined hour during the day or night.

Such equipment has been devised and models of it have been installed both in the National Research Laboratories and at the University of Manitoba. It has increased the precision of the malting

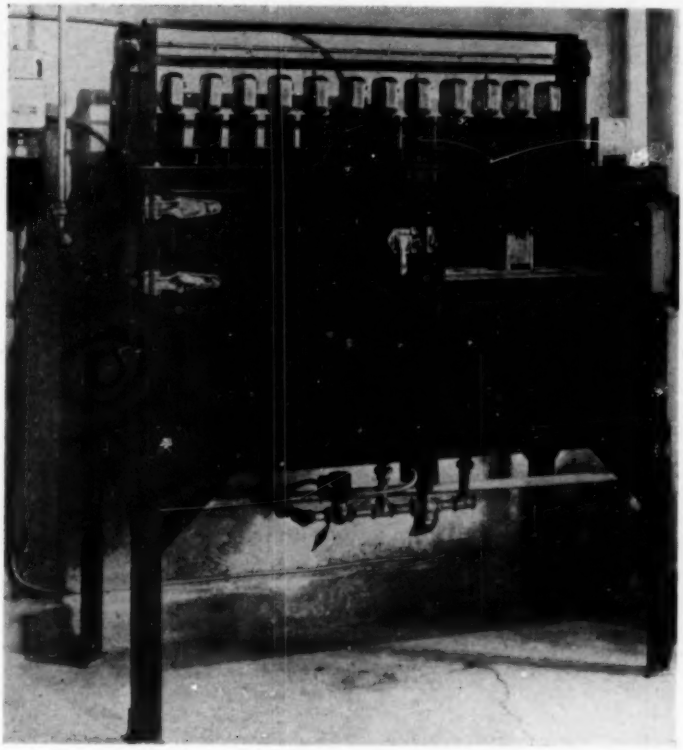

Fig. 1. Steep tank.

test and has also made it unnecessary for members of the malting staff to visit the laboratories outside of working hours for the purpose of attending to steeps.

The first of these new steep tanks was designed in Ottawa and constructed partly from pieces of the old equipment. When it had been shown that it operated satisfactorily, an improved model was designed, built by a Winnipeg firm, and installed at the University of Manitoba. It is this model that is described in this paper.

Description of Equipment

The equipment consists essentially of a long narrow steep tank standing inside a larger insulated water tank. The inner tank is connected to the large tank and to waste by pipes fitted with solenoid valves operated by an electric time switch. This mechanism permits the inner tank to be drained and refilled automatically at intervals, thus providing changes of water and periods of aeration for the samples in the inner steep tank. A second automatic feature, consisting of a battery of alarm clocks, makes it possible to drop samples into the steep tank at predetermined times.

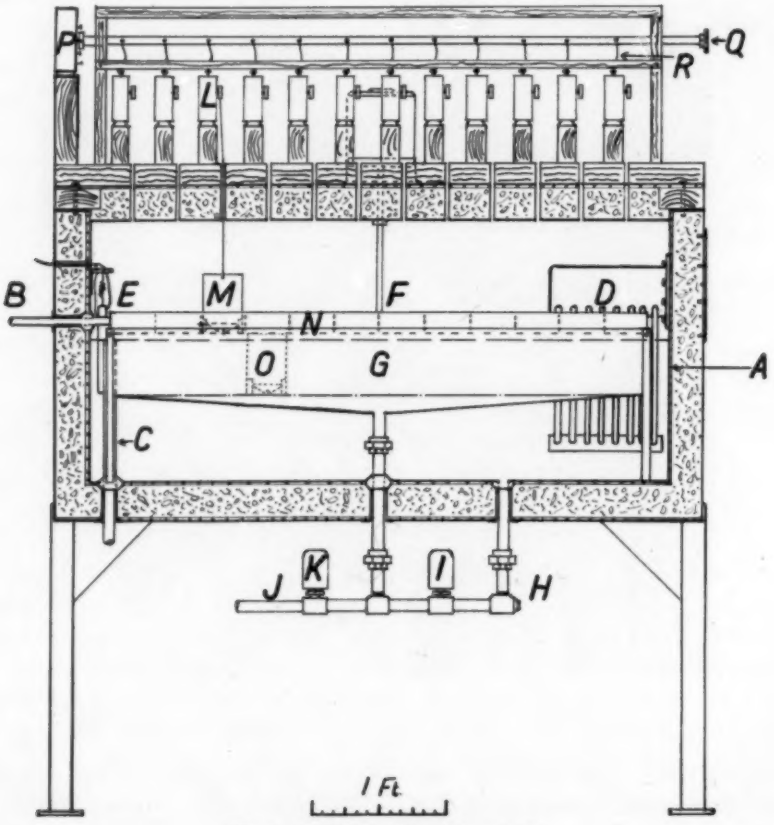

Fig. 2. Front elevation of steep tank.

A photograph of the equipment is shown in Figure 1 and details of its construction are given in Figure 2, which shows the front elevation of the unit in section. The large tank *A* is constructed of $\frac{3}{16}$" boiler plate insulated with three inches of cork, and enclosed in an outer casing with $\frac{5}{16}$" boiler plate bottom and 18 gauge sheet metal sides.

The cover of the tank is removable and of the same construction with boiler plate top and cork insulation protected by sheet metal. The water level in the tank is kept constant by a float valve attached to the water inlet *B*. There is also a standing waste which is shown at *C*. The flow of refrigerant through the evaporator coil *D* is controlled by the mercury in glass thermoregulator *E*. This is connected to a relay in the live line to the compressor motor (not shown in the drawing), throwing it on and off as required. The water in the tank is circulated by a stirrer shown at *F*.

The inner tank *G* in which the samples are steeped is constructed of 14-gauge galvanized iron. It holds twenty-four 250-g. samples, each in a galvanized iron cage (Fig. 3) with holes in the bottom to allow

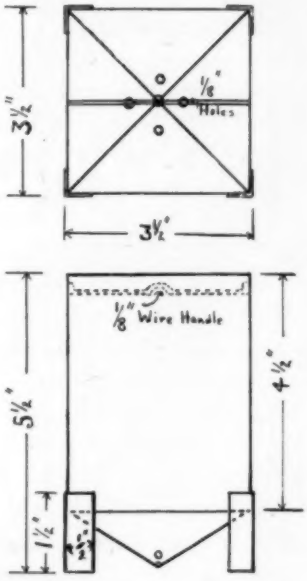

Fig. 3. Steep cage.

entrance of water. These cages rest on a false bottom of wire mesh (6 mesh) during steeping. The inner and outer tanks are connected by the ¾" pipe *H* in which the water flow is controlled by the solenoid valve *I*. The valve is normally open so that the water in the two tanks stands at the same level. The connections to waste are seen at *J* with a normally closed solenoid valve *K* in the line.

The alarm clocks *L* by which the cages are dropped are mounted on individual wooden blocks, and these blocks are in turn mounted on a 6" × 2" plank laid on top of the tank cover. The cages are suspended from the alarm winding key of the clocks by piano wire and

curtain rings. A cage is shown suspended from a clock at *M*. The bottom of the cage fits into guides *N* so that when the alarm rings and the alarm key turns the cage drops cleanly into the water as shown at *O*. The alarm clocks have twelve-hour movements, but a twenty-two-hour control is supplied by the master clock *P*. The alarm wind of this clock is attached to a shaft *Q* to which the alarm-release pins of the other clocks are attached by string as shown at *R*.

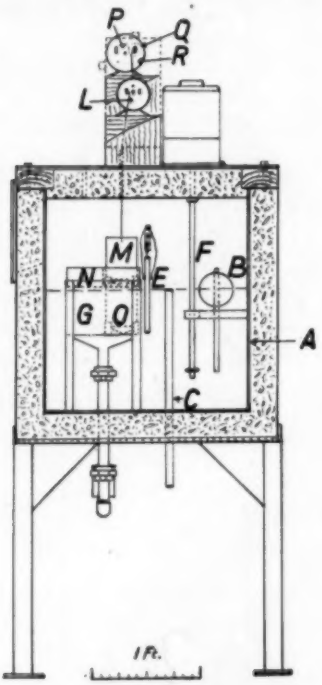

Fig. 4. Side elevation of steep tank.

A side view of the equipment is shown in section in Figure 4. This diagram shows that the inner tank *G* is situated close to the doors in the front portion of the large tank. The space behind the inner tank is occupied by the cooling coil (not shown), stirrer *F*, float valve *B*, standing waste *C*, and thermoregulator *E*.

Operation of Steep Tank

The steep water is thermostatically controlled at 10°C. and only the water that is drained from the inner tank twice daily is replaced. This draining is done by the action on the solenoid valves of an electric clock with automatic switch gear. The clock is set so that the current is applied to the valves at 8 A.M. and 8 P.M. each day. When this hap-

pens valve *I* closes and shuts off the supply of water to the inner tank, while valve *K* opens allowing the water in the inner tank to flow to waste. The valves are maintained in this position for one hour. At the end of the one-hour aeration period the current is shut off by the clock and the valves return to their normal positions. The valve on the waste outlet closes and the valve on the connecting line between the inner and the outer tank opens. The water in the inner tank rises to the level of that in the outer tank, which is maintained by means of a supply line controlled by a float valve.

The practice of this laboratory (Manitoba) is to malt in batches of twelve, so that only twelve clocks are required for dropping the samples into the steep. Allowance has been made in the inner tank for 24 samples as it is sometimes necessary to start steeping samples in a second batch before the first batch is removed.

In preparing a batch, each sample is suspended from its respective clock, the alarm of which is set to ring at the hour that the sample should go into the steep. If the sample is to drop into the steep within 11 hours the alarm release is taken out. When the alarm rings the winding key revolves and the curtain ring slips off, dropping the cage.

When the sample should go into the steep after 11 hours the master clock mechanism *P* is brought into use. The alarm releases on the clocks have been altered and made completely removable, and they are tied to the shaft *Q* operated by the alarm wind of the master clock. The alarm of the master clock is set to ring 11 hours from the time of preparation, so that the clocks bearing samples to go in after this interval have the alarm releases left in for the first 11 hours and these are subsequently pulled by the master clock. Since clocks do not ring while the alarm release is in, clocks controlled by the master clock do not drop samples until after 11 hours. The clock mechanism thus makes it possible to drop 12 samples into the steep, each at the required time, during the 22 hours after the mechanism is set.

Removal of Samples from Steep

At the end of the steeping period the cages are drained by hanging them inside the tank for 30 minutes. They are then removed and the few drops of water still adhering to the barley are removed by suction. A cup that fits the bottom of the cages is attached to a suction flask, which in turn is connected to a water pump. The samples are then weighed and transferred to the germination cages (Anderson and Rowland, 1937). Adjustment to the desired moisture content of 44% can be made by adding a few grams of water or by removing a few grams with blotting paper as reported by Sallans and Anderson (1939).

Precision

The clocks drop the samples into the steep within five minutes of the setting time and have proved entirely satisfactory. Over the six-month period that the equipment has been in use at the University of Manitoba the average amount by which the steeped samples have differed from the required weight of 446 g. is 3.4 g. The standard deviation is 4.5 g., which shows that the error of steeping is only 1.0%. The errors of the Ottawa equipment are of the same order. These errors represent the combination of the error of estimate from the pilot steeps and the actual error of steeping. The equipment therefore possesses a very satisfactory level of precision.

Summary

Laboratory steeping equipment for twenty-four 250-gram samples is described. The steep tank is built into a larger water tank which is thermostatically controlled at 10°C. The steep tank is connected to the large tank and to waste. Solenoid valves, operated by an electric time switch, permit the steep tank to be automatically emptied and refilled, thus providing aeration and a change of water for the samples.

A second automatic feature, consisting of 13 alarm clocks, permits each individual sample to be dropped into the steep tank at the required time, at any hour of the day or night. The length of time required for each sample to steep to a moisture content of 44% is determined by a pilot steeping test. The combined error of pilot test and steeping is quite small. On the average, samples are within 3.4 g. of the required weight when they are removed from the steep tank. The standard deviation is 4.5 g. and represents a steeping error of 1.0%.

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CONTROL OF DOUGH TEMPERATURE DURING FERMENTATION[1]

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(Read at the Annual Meeting, May 1939)

Last year in reporting on a co-operative test of a punching and moulding machine (Malloch, 1939), it was suggested that factors other than the manipulation of the dough contribute materially to the variability of test baking. Since temperature has a marked effect on all the processes involved in dough fermentation and on the colloidal behaviour of dough, it seemed logical to examine the adequacy of the control of dough temperature at the various stages of test baking, and the fermentation stage was chosen as a starting point.

Dough Temperatures in a Fermentation Cabinet

Experiments were conducted to check the consistency of dough temperatures in the fermentation cabinet in use in this laboratory. The cabinet is an air thermostat similar to that described by Larmour, Machon, and Brockington (1931) operated at the normal temperature of 30° C., in which the doughs are fermented in covered earthenware crocks. The doughs under study were placed in these crocks and four thermocouples were inserted. Two were pushed well into the centre of the dough from the bottom and the top respectively and the others were located in the outer layer at either side. A fifth thermocouple was placed in the cabinet close to the crock. Measurements were made periodically without punching the dough or opening the door of the cabinet.

In the first experiment the dough was mixed at approximately 28° C., and on standing in the cabinet the temperature gradually rose until it reached cabinet temperature after 70 minutes of fermentation. The temperature continued to rise until at 90 minutes it was nearly half a degree above cabinet temperature. After the first 30 minutes, variation between the different parts of the dough was small. The results are shown graphically in Figure 1.

In the second experiment (Fig. 2) the dough was mixed above cabinet temperature. A reading taken by thermometer immediately after mixing showed 32° C. The temperature of the dough rose slightly at the beginning of fermentation and then fell steadily to the

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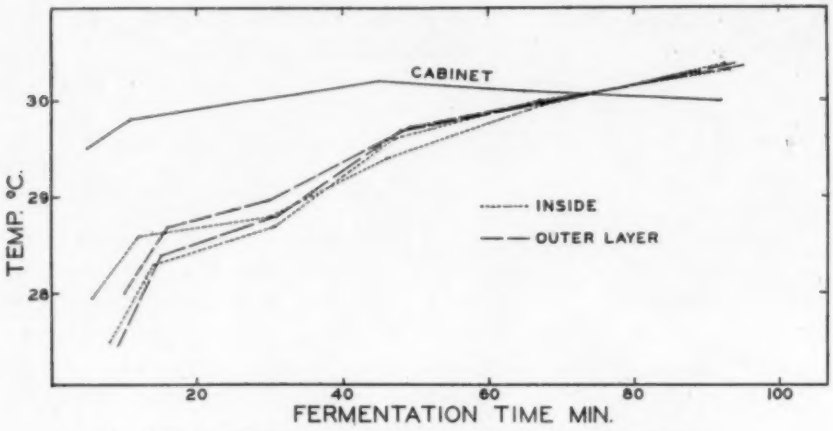

Fig. 1. Temperature of a dough mixed below cabinet temperature.

end of the experiment but had not reached cabinet temperature at 150 minutes. As the temperature fell the spread between the outside and the inside of the dough decreased but at 150 minutes the outer couples were 0.5° C. above the cabinet temperature while the inside of the dough was 1° above.

The air thermostat failed to bring the doughs to, and to maintain them at, the required temperature. It therefore cannot be relied upon to correct for the differences in temperature after mixing which are found between flours of different characteristics. Three factors are responsible for the unsatisfactory results. The heat transfer between a solid and the surrounding air is notoriously bad. The fer-

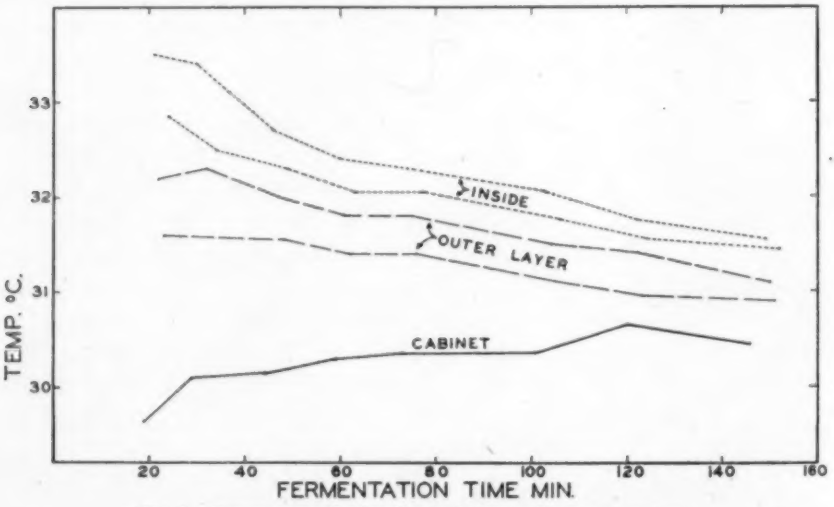

Fig. 2. Temperature of a dough mixed above cabinet temperature.

mentation reaction is exothermic and efficient transfer is necessary for the removal of the heat generated. Dough has a fairly high insulating value because of its porous structure and the heat transfer from one part of the dough to another is relatively slow. The temperature of the cabinet was reasonably uniform throughout each experiment and, while some improvement in heat transfer might be accomplished by forced-air circulation and by the use of metal containers, it is doubtful if any air thermostat is satisfactory for the control of dough temperatures in test baking or in any other test.

Comparison of Water and Air Thermostats

To determine whether the variability in test baking results could be reduced by use of a water thermostat to replace the cabinet for storage of fermenting doughs, temporary equipment was constructed. It consisted of ten metal containers suitably supported, immersed in a water bath, and provided with loose covers. Three flours were used in the experiment. Each of these flours was baked on ten different days. On each day ten doughs were fermented in the new equipment and ten in the old cabinet. Three extra loaves were baked at the beginning and end of the series and discarded. Thus the results of 300 bakings using each method of temperature control were available for calculation of the variability.

In previous studies of experimental baking in this laboratory (Malloch and Hopkins, 1935) it was not possible to combine the results obtained on different days because of the instability of the variance. The daily variability in the present experiment was calculated and found to be reasonably constant. Only three of the sixty groups gave standard deviations which were significantly different from the appropriate average of the daily deviations. In two of these cases the increased variability can be attributed to the abnormal volume of a single loaf; in the third, two loaves were concerned. Since the variance is reasonably stable it is possible to consider all the results for each flour together. The variability of each flour by the two methods of temperature control is given in Table I.

TABLE I

Effect of Fermentation in Water Bath on Variability in Loaf Volume

Flour	Standard deviation	
	Cabinet	Water bath
	cc.	*cc.*
A	15.9	13.6
B	15.9	13.7
C	14.5	12.8

There was a reduction in variability by use of the water bath with all three flours. The values given include variations from all sources, between days, within days, and random error. The data were subjected to an analysis of variance to ascertain the distribution of the variability between these sources. The results of this are summarized in Table II.

TABLE II

ANALYSIS OF VARIANCE

Variance due to	D.F.	Mean square flour *A*		Mean square flour *B*		Mean square flour *C*	
		Cabinet	Bath	Cabinet	Bath	Cabinet	Bath
Days	9	.092[1]	.066[2]	.097[2]	.076[2]	.136[2]	.117[2]
Replicates	9	.015	.037[2]	.034[1]	.016	.023[2]	.022[2]
Random error	81	.019	.011	.016	.013	.008	.005
Standard error (*cc.*) (calculated from random error)	—	13.9	10.6	12.8	11.4	8.9	6.8

[1] Exceeds 5% point. [2] Exceeds 1% point.

The differences between days are significantly greater than the random error in all series. However, the water bath gives more constant results. In four series there was a systematic error within days (referred to as "replicates" in the table). This arises from the characteristically low or high values obtained for loaves of the same number in the series throughout the different days baking. With flour *A* this systematic error was higher when the bath was used but the reverse was true of the other two flours. The loaves fermented in the water bath gave a lower random error with all flours.

The original data were examined to find the source of the systematic variations within and between days. The pertinent results are summarized in Table III.

Throughout the entire experiment the values obtained on the first day on which each flour was baked were characteristically low. This is almost entirely responsible for the significant variance "between days." Since none of the flours were baked on ten successive days and the flours were baked at different times it is difficult to see that this behaviour can be explained on the basis of consistent differences in the equipment or baking technique on those particular days. The explanation that the equipment had not been in continuous use is certainly not valid. The only possibility which remains is that the sampling of the bulk of flour was faulty, and this may have been the case. In

TABLE III

SOURCE OF SYSTEMATIC VARIATIONS

Flour	Treatment	Loaf volume		
		General mean	Mean, Day 1	Mean, Loaf 1
		cc.	*cc.*	*cc.*
A	Cabinet	646	627	646
	Bath	653	636	547
B	Cabinet	752	738	740
	Bath	750	734	749
C	Cabinet	651	622	646
	Bath	662	636	652

the four series where there were significant systematic differences between replicates, the first loaf of the series was characteristically lower in volume than the general mean. It is possible that the three extra loaves which were included with each series were not sufficient to allow the equipment and particularly the oven conditions to become stable. The inclusion of four or more extra loaves would probably have reduced the variability in the experimental series.

Discussion

It is evident from these results that the conventional fermentation cabinet is not satisfactory equipment for controlling dough temperatures and that the use of a water bath for this purpose reduces the variability. A further reduction can probably be made when permanent equipment is constructed as the covers of the containers used in this experiment did not fit uniformly well and there were differences in the degree of skinning of the doughs, which probably affected the loaf volume.

The systematic errors found in this experiment are relatively small but nevertheless they will be investigated with a view to their removal. The random error has been reduced to a point only a little above a satisfactory level. Attempts will be made to reduce this error still further. The success of improved temperature control at one stage of baking in reducing the variability makes an examination of the possibilities of improving other stages highly desirable. This work is now in progress in this laboratory. A water-jacketed mixer has been constructed, a suitable proof box has been designed and is under construction, changes have been made in the wiring of the oven, and alterations are being made in the air-conditioning equipment to give improved control of temperature.

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PREDICTION OF BAKING VALUE FROM MEASUREMENTS OF PLASTICITY AND EXTENSIBILITY OF DOUGH. I. INFLUENCE OF MIXING AND MOLDING TREATMENTS UPON PHYSICAL DOUGH PROPERTIES OF TYPICAL AMERICAN WHEAT VARIETIES

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The physical properties of the gluten complex of a dough are in a continuously changing state, the rate of change being contingent upon the treatment accorded to the dough, its age, the proportion of water used for its preparation, and other variables. In such a complex and heterogeneous dynamic system, a single measurement of a physical property or properties is of limited value. A record of the continuously changing state of the dough as a function of the customary dough treatments including mixing, resting, molding, etc., should prove much more valuable.

The farinograph is adapted to the measurement of dough plasticity as a function of continuous mixing. This instrument has also proved successful in estimating the capacity of a strong flour to yield doughs of acceptable properties when blended with weak flour. From the characteristics of farinograms other dough properties, such as the rate of hydration, sensitivity to mixing, and buckiness, can be estimated. The farinograms are of limited value in certain other particulars, however. Thus they fail to reveal the direction and magnitude of the effect of chemical treatments, or the recovery or tendency of the dough to regain certain of its original properties after excessive mixing. It has been shown recently that these treatments are mainly registered in doughs at rest. In this condition doughs exhibit distinctly different properties from those shown when they are in an "excited" condition, as effected for instance by mixing, molding, or other dough manipulations. We probably deal here with a process analogous to "work hardening" known in other fields of physics.

To measure the strain and stress relationship of doughs at rest it was necessary to return to measurements of extensibility. Such measurements have been made at times in the past when the dough was still in an "excited" state, that is, when it was freshly mixed or shaped. An instrument recently devised by Brabender and known as the extensograph (Fig. 1) provides opportunity for determining extensibility after permitting the dough to rest for suitable intervals of time. In this paper the effects that physical treatments of the dough, such as mixing and molding, have upon the dough properties that are involved in extensibility, will be shown.

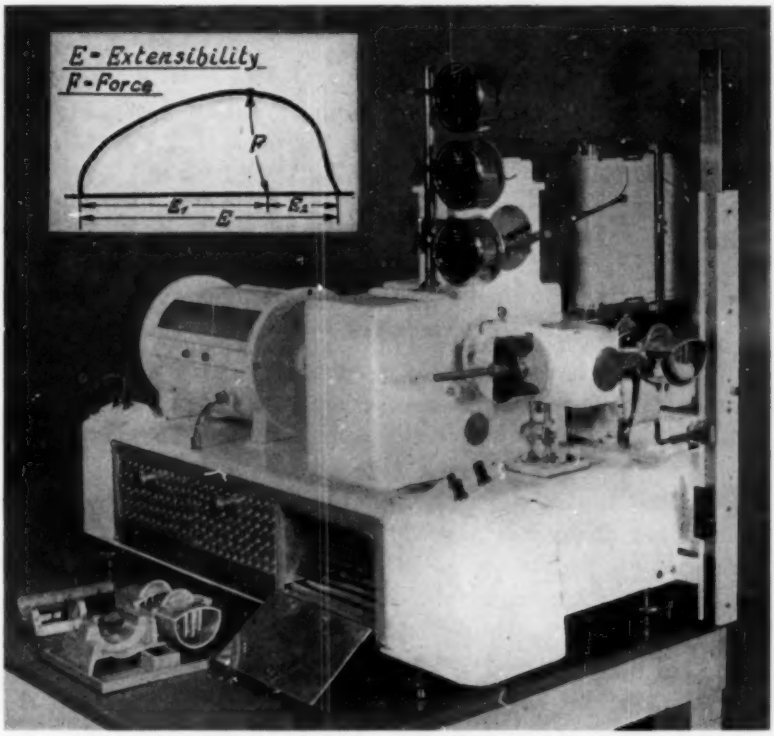

Fig. 1. Photograph of extensograph, with insert of schematic extensogram.

In these studies the doughs were prepared in the following standard manner: 300 g. of flour plus 6 g. of salt were mixed in the farinograph to a consistency of 500 units. After mixing for exactly 5 minutes the machine was stopped, the dough removed, and two portions of 150 g. each were rounded up by means of the device that is a part of the extensograph ensemble. These smoothly rounded masses were passed once through the molder that is provided with the instrument, and were then clamped firmly in the dough holder. They were placed in

the thermostat or fermentation cabinet for 60 minutes, unless otherwise indicated, and then subjected to extensibility measurements. This treatment was repeated at intervals as described in the later portions of this paper. Extensogram constants computed and recorded in certain of these studies are referred to by symbols as follows (Fig. 1):

F = force applied to extend the dough at constant speed of extension, measured along the vertical axis of a typical extensogram, one unit being equal to 1.6 g.[1]

E = extensibility, 1 cm. (10 units) on the horizontal axis of the diagram corresponds to an equivalent dough extension of the original dough length. For instance at 10 cm. the dough is extended about 10 times its original length.

E_1 = length of extension at optimum point of resistance to extension or force.

Velocity of graph paper = 6.5 mm./sec.

Velocity of dough hook = 13.6 mm./sec.

Area = *area under* the extensogram recorded in units of 0.1 cm^2.

Changes in Stress/Strain Relationship of Doughs as a Function of Rest Time

It is common baker's knowledge that doughs from various flours respond quite differently to fermentation and to the customary dough treatments during fermentation, the differences being evident not only in gas production but in physical dough characters as well. Cereal chemists have studied such relations quite extensively by means of the baking test, but exact physical measurements had so far not been reported, mainly because of lack of suitable apparatus. The extensograph enables certain work to be done in this direction. Studies were conducted on (*a*) fermenting doughs, using various amounts of yeast; (*b*) doughs containing no yeast and only 2% salt (regular procedure); (*c*) doughs containing 2% salt and lactic acid sufficient to obtain a pH of 5.4.

Since the direction of changes during resting or fermentation were the same in all three procedures, we shall report here for the sake of brevity only the experiments of the series *b*.

Changes in dough structure of a strong and a weak flour were studied in three stages after mixing, namely immediately, and after two and four hours of rest, respectively. In each instance the molded masses of dough were allowed to stand for varying intervals up to 120

[1] The standard procedure used at Duisburg at the present time deviates in the following points: (*a*) one unit of resistance to extension corresponds to a force of 1.25 g.; (*b*) time of rest is 45 minutes; (*c*) doughs are mixed one minute, rested 5 minutes, and mixed for another 3 minutes.

minutes and the extensograms were made from time to time during this period. The area and the ratio F/E were then computed, with the results expressed graphically in Figure 2 for the strong flour, and in Figure 3 for the weak flour.

In Figure 2, involving a dough made from strong American spring-wheat flour, it is apparent that its extensibility increased and the resistance to extension decreased when the dough was permitted to stand for a long time after it had been excited by molding. As the dough grew older, *i.e.*, when the molding was done two or four hours

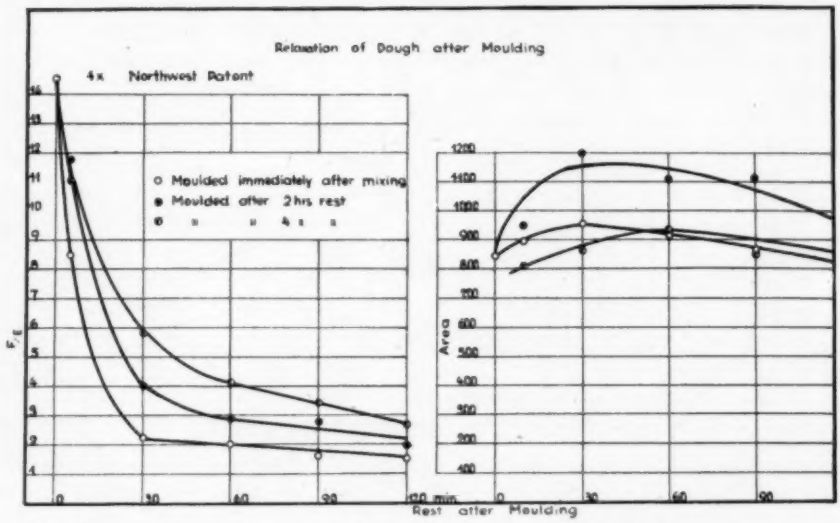

Fig. 2. Change of F/E relationships and of areas under extensograms on resting of dough made from strong flour.

after mixing, the relaxation from the excited state as induced by molding proceeded at a slower rate. Thus when the comparisons were made 30 minutes after molding, the F/E ratio of the freshly mixed dough had receded to 2.2, while the F/E ratio of the four-hour dough was 5.8.

The weaker European blend involved in the studies, recorded graphically in Figure 3, yielded a dough which behaved entirely differently. The F/E ratios of the freshly mixed and the two-hour and four-hour doughs did not materially differ when compared 30 or 60 minutes after molding. In fact such differences as were encountered appear to be in the reverse order from the strong-flour doughs, since there was evidence of an increased rigidity in the structure on aging of the latter. It will be demonstrated in a succeeding article that the change in relaxation on aging is not only dependent upon the kind of flour and variety of wheat but also upon the customary chemical treatments or the age of the flour.

The term "relaxation" as used above is not quite analogous to the Maxwell's "relaxation time" discussed by Schofield and Scott Blair. Halton and Scott Blair (1936a, 1936b) associated this term with "spring" and arrived at it by separate determinations of dough viscosity (η) and shear modulus (n).

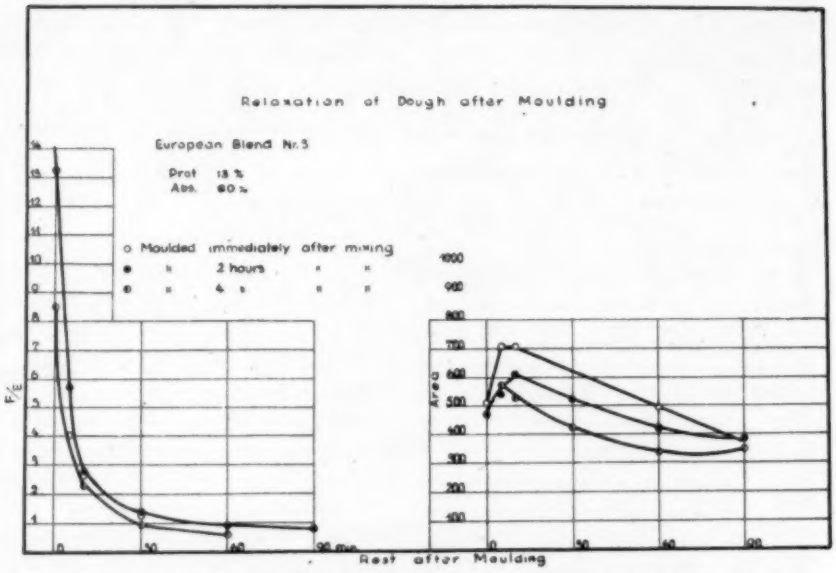

Fig. 3. Change of F/E relationships and of areas under extensograms on resting of dough made from weak flour.

Change in Dough Extensibility with Extended Mixing

Bohn and Bailey (1936a, 1936b) reported that stress readings taken at different stages during dough mixing were proportional to the corresponding consistency values of the farinograph. The hysteresis effects of different degrees of dough mixing were not included in their studies. We devoted our attention especially to the effect of mixing and to aged doughs.

Practical baking experience has generally resulted in the conclusion that fermentation time may be reduced by extending the mixing time.[2] The study of fermentation tolerance is thus dependent upon a complete knowledge of the kneading or mixing treatment. Furthermore, a discussion of the "optimum" in the instance of either mixing time or fermentation time would involve a specification of the other variable. Flours can be "mixing sensitive" because of weak gluten structure, where the gluten is actually damaged by overmixing or tight gluten character, in which overmixing accentuates buckiness. In the latter

[2] Exceptions have been noted in the instance of certain Canadian flours.

case mixing sensitivity is usually proportional to sensitivity towards oxidizing agents.

Under conditions such as prevail in bakeries in the United States the first kind of mixing sensitivity is encountered mainly in some of the weaker southwestern wheat varieties; for instance Blackhull. An extensive study of the mixing tolerance of southwestern flours revealed that if flours of about equal protein content showed decided differences in their respective farinograms, such differences were reflected again in the mixing sensitivity of these flours. In these experiments mixing was done by means of a Hobart vertical high-speed mixer, and the other baking operations were carried out on a semi-commercial basis. The fermentation time was varied from three to five hours, and the doughs were proofed to standard height. Mixing intensity was limited to three degrees, namely:

For normal mixing	1 minute, low speed
	1 minute, medium speed
	2 minutes, high speed
For overmixing	4 additional minutes, high speed
For severe overmixing	8 additional minutes, high speed

The flours were classified into the following three groups according to their protein content:

Group A = 13.0–15.0% protein
Group B = 11.5–13.0% protein
Group C = 10.5–11.5% protein.

Each group was divided into three sub-groups according to general strength rating on basis of the farinogram. Besides the general appearance of the curve, the "developing time" served mainly as criterion of classification, thus:

Sub group I had 9–12 minutes "developing time"
Sub group II had 6– 9 minutes "developing time"
Sub group III had 6 minutes "developing time."

Subgroup *I* stood severe overmixing very well, while subgroup *II* was slightly and subgroup *III* severely damaged, a fact which showed up especially at longer fermentation times. In the high-protein group overmixing was not quite as injurious as in the two lower-protein groups.

Looking at the problem from the standpoint of the commercial baker it seems that the hazard of damage to the gluten structure on account of overmixing might be limited to flours of subgroup *III*. The commercial baker mixes to the dry point, and sometimes continues

a little beyond if he desires to raise the temperature of the dough. Such drastic mixing as was accorded in our experimental studies does not occur in such commercial practices.

Mixing sensitivity because of tight gluten structure is probably encountered more frequently. We have therefore given this problem special attention. Two flours of about equal protein content, 12.7% and 12.5%, marked *GM3* and *GM5* respectively, afforded an interesting comparison. From their farinograms, recorded in Figure 4, it might

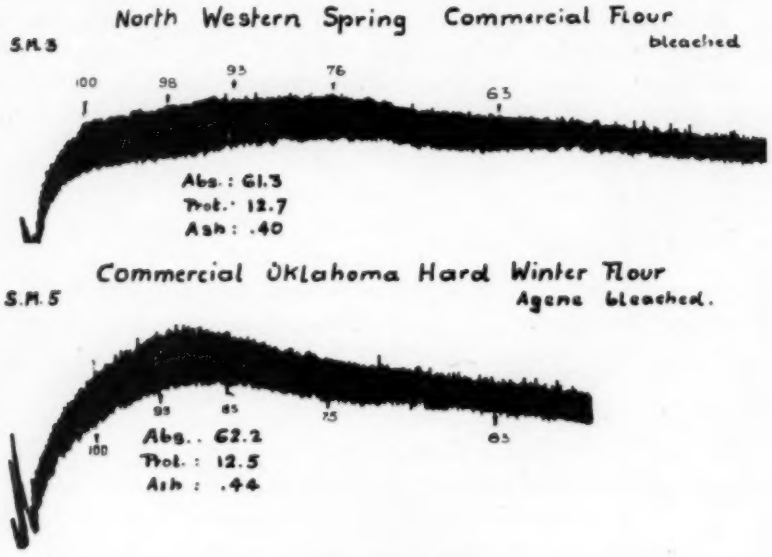

Fig. 4. Farinograms of *GM3* and *GM5*.

be assumed that the northwestern spring-wheat flour *GM3* would evidence greater mixing resistance than the Oklahoma or southwestern flour *GM5*. To test this assumption, doughs made from both flours were subjected to varying mixing treatments, being removed from the farinograph mixer after 3, 5, 7, 10, and 15 minutes of mixing, respectively. These doughs were then subjected to tests in the extensograph after having been permitted to rest for varying intervals up to 7 hours. The results of these tests, together with a graphic record of the volume in cc. of test loaves fermented for varying periods as shown, are recorded in Figures 5 and 6. In order to eliminate the gas-production factor as much as possible 5% of sugar and 0.25% of diastatic wheat malt flour were added to the dough. Otherwise the A.A.C.C. standard baking test method was followed with the exception that $1\frac{3}{4}$% of yeast was used. This formula should provide for sufficient gas production up to 4 hours of fermentation.

From Figure 5 it is apparent that when the southwestern wheat flour dough, accorded extended mixing (15 minutes), was promptly tested for extensibility, the area of the extensogram was reduced substantially below that of the dough mixed for 3 or 5 minutes; for example, the curve area for the 15-minute mixing period is only 230 units as compared with 900 units for the three-minute mixing time. When the dough mixed for 15 minutes was permitted to rest for several hours after mixing, however, the area of the extensogram increased markedly,

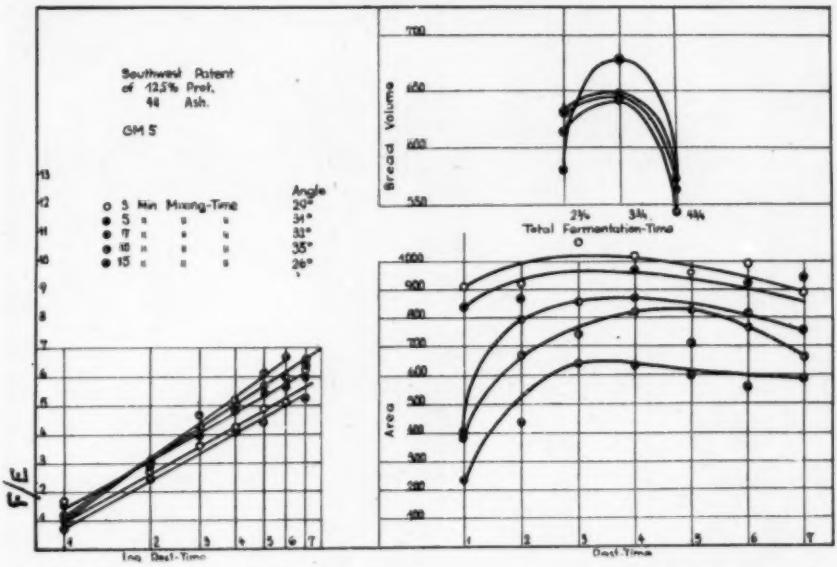

Fig. 5. Changes in *F/E* relationships of extensograms, plotted against the logarithm of resting time of doughs made from *GM5*; area under extensograms of doughs on resting; loaf volume in cc. of bread baked from doughs fermented for varying time intervals.

reaching 630 units after 3 hours. A somewhat similar behavior was observed in the instance of the dough mixed 7 and 10 minutes respectively. At the same time the general shape of the curve was altered, as evidenced by the *F/E* ratios recorded graphically at the left of the figure.

These changes in area are in sharp contrast with the behavior of analogous doughs prepared from the northwestern wheat flour *GM3*. In this instance the dough mixed for a long period (15 minutes) gave an extensogram of larger area (520 units) than the corresponding southwestern wheat flour dough, but there was little increase in area on standing, and at the end of three hours the area was actually less in the northwestern than in the southwestern flour dough. These differences in the extensograms are well supported by the practical baking test. Thus in Figure 7 where photographs of the test loaves are shown, it is

evident that the southwestern flour doughs (marked *S* on the loaves) recovered from the heavy mixing treatments on fermentation and gave larger loaves of good texture than the northwestern wheat flour doughs (marked *N* on the loaves).

Thus in our experiments the northwestern flour dough is more mixing-resistant only when the doughs are tested one hour, or, at a maximum, two hours after the mixing process. Later the gluten tightening has proceeded to such an extent that the dough becomes too short for a large extensograph area or for normal baking behavior.

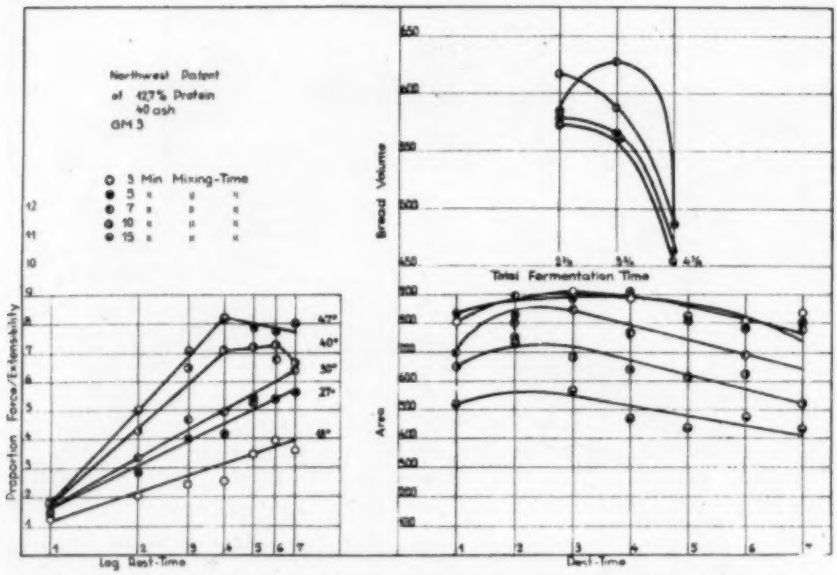

Fig. 6. Changes in *F/E* relationships of extensograms, plotted against the logarithm of resting time of doughs made from *GM3;* area under extensograms of doughs on resting; loaf volume in cc. of bread baked from doughs fermented for varying time intervals.

The tightening of the gluten structure is suggested by the progressive change in the *F/E* ratio, which is plotted against the logarithm of time in hours in Figure 6. Note that these graphs approach a straight line for the first four hours, and that they diverge from one another in the instance of the several doughs accorded different mixing treatment. Among the corresponding southwestern flour doughs such divergence is much less apparent. Moreover, the angles which these graphs form with the horizontal or axis of abscissae are greater in the northwestern flour doughs at 10 or 15 minutes of mixing, which affords added confirmation of the greater tightening action resulting from extended mixing.

Accordingly it is concluded that the slope of the farinograph curve after the point of maximum consistency is not always a measure of

mixing tolerance. This is only the case when one deals with weaker flours of similar character, as for instance in the comparison of the different southwestern wheat varieties.

The differences obtained in our experiments are probably somewhat exaggerated through the particular action of the farinograph mixer.

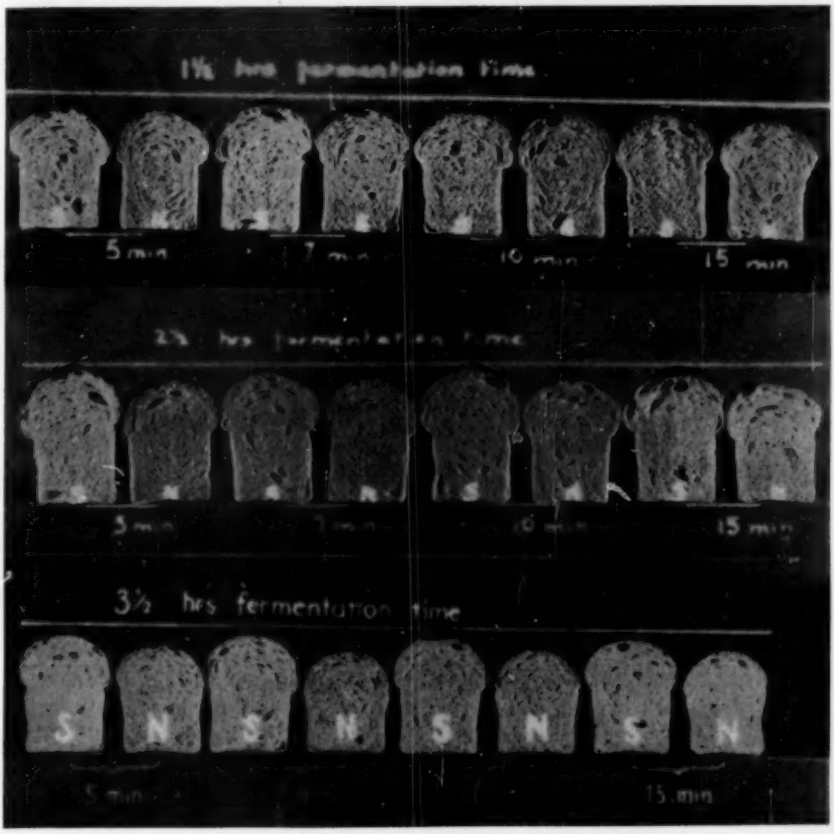

Fig. 7. Photographs of loaves baked from southwestern wheat flour *GM5* (marked *S*) and north western wheat flour *GM3* (marked *N*).

It is possible that the customary high-speed mixer will not give differences of the same magnitude. Furthermore the flours were already several months old at the time of testing and therefore already somewhat short in character. Since we are discussing fundamentals rather than evaluating flours, the magnitude of the differences does not play a big role, however.

While the increased tightening effect on the gluten with extended mixing sufficiently explains why a stronger flour can actually be less

"mixing resistant," there is still the question as to why the high-speed mixer proved to be especially successful on the tougher and stronger northwestern flours. The question is: Does high-speed mixing actually provide more extensive mixing treatment, or does it develop slacker doughs better than is possible with slow-speed mixing? From the observation that stiff doughs are developed better than slack doughs in the farinograph mixer (other slow speed mixers produce similar effects), even if the total work input is the same in both cases, it is concluded that the alternating intensity of compression is one of the major factors

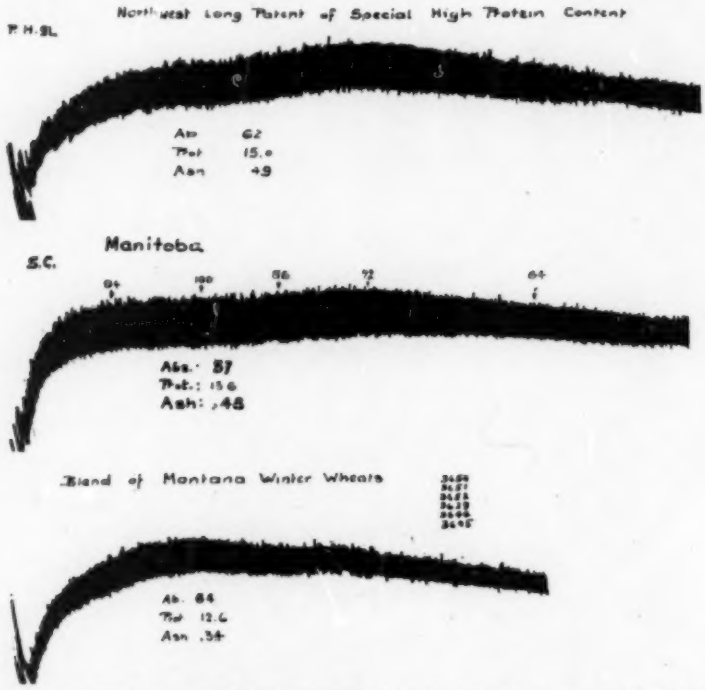

Fig. 8. Farinograms of high protein northwestern spring-wheat patent, Manitoba *SC*, and Montana winter wheat flours.

in dough development. Slow-speed mixers do not seem to develop enough compression on slack doughs. Actually about 2% more water is incorporated by the Hobart high-speed mixer (two-gallon bowl) than by the farinograph mixer, on the basis of the same farinograph consistency. Furthermore a dough developed in the high-speed mixer gives a farinogram with a wider band than one developed from the beginning in the farinograph mixer. Since the northwestern flours tighten up considerably during fermentation, the development of slack dough becomes of major importance. It is therefore believed that the high-speed mixer was successful, mainly because it develops slacker dough more

efficiently, thus giving a smoother and more elastic dough, and not because of added or more intensive mixing treatment.

Some other observations seem to indicate that the farinograph and some other types of slow-speed mixers incorporate more air (O_2) into the dough. This is analogous to added oxidation treatment, which is usually detrimental to the already tough spring-wheat flours.

Flours *GM3* and *GM5* afforded means of comparing such types of flours, since they give farinograph curves of nearly equal "developing time" (mixing time to the point of either decrease in curve width or

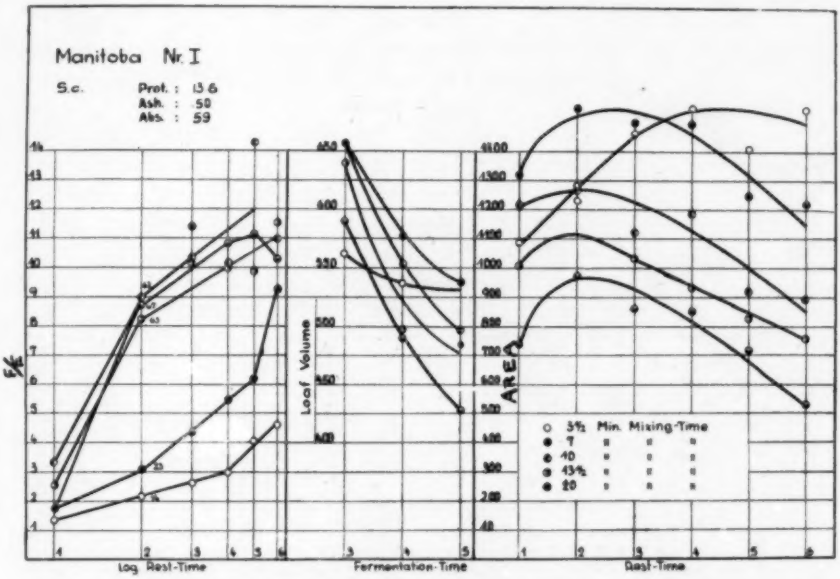

Fig. 9. Changes in *F/E* relationships of extensograms, plotted against the logarithm of resting time of doughs made from Manitoba *SC:* area under extensograms of doughs on resting; loaf volume in cc. of bread baked from doughs fermented for varying time intervals.

decrease in consistency—in the case of *GM3* 6½ minutes and in the case of *GM5* 6 minutes) but they differ in the slope of consistency decrease after this point. The northwestern long patent and the Manitoba flour, the farinograms of which are shown in Figure 8, afford a comparison of flour types of equal "developing time" and equal consistency decrease after this point, being different however in the slope of the initial part of the farinograph curve. Extensograms of doughs mixed for increasing intervals of time, and allowed to rest for periods up to five or six hours, disclosed a greater sensitivity to overmixing of the Manitoba flour *SC*. Thus after five hours of rest the extensogram area (Fig. 9) of the dough mixed 20 minutes was about 850 units less than that of the dough mixed 3½

minutes. The corresponding decrease for the northwest long patent *PHG1* (Fig. 10) was only about 450 units, or less than half as much. The loaf volumes of test loaves baked from doughs mixed for varying periods of time are in sharp contrast in the instance of these two flours and support the extensograph tests. Likewise the *F/E* ratios recorded as a function of the log of time show a decided difference between these two flours. Thus the angle, used here to express the change in dough tightening with time, increased 40°, from 23° to 63°, with the Manitoba flour and only 13°, from 22° to 35°, with the northwestern long patent, when the mixing time was increased from 7 to 10 minutes.

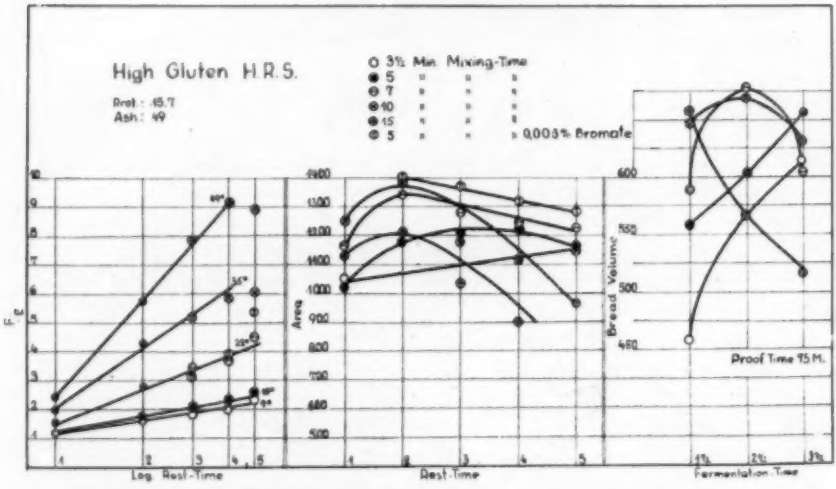

Fig. 10. Changes in *F/E* relationships of extensograms, plotted against the logarithm of resting time of doughs made from high-protein northwestern spring wheat patent; area under extensograms of doughs on resting; loaf volume in cc. of bread baked from doughs fermented for varying time intervals.

It has been known of course that fast initial rise of the farinograph curve is indicative of compact gluten character in fairly strong flours, but it usually was not sufficiently realized that doughs of this character are tightened to such a degree by overmixing. Considering the bucky dough problem from this angle it is realized at once why "trouble shooters" always find it best to give such flours little mixing and few "take-ups," rather than longer mixing time, which evidently would render the dough more extensible.

Similar conclusions can be drawn from mixing experiments carried out with flours experimentally milled from two northwestern wheats, Reward and Ceres. Their farinograms (Fig. 11) indicate Reward to be of relatively tight gluten character. The expected higher mixing sensitivity is evident from the extensibility measurements graphically

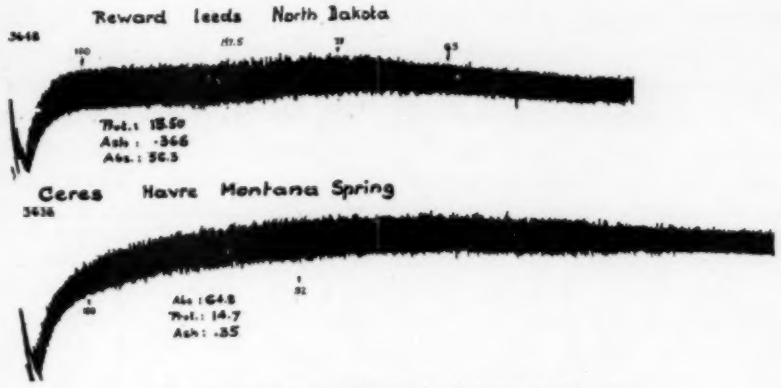

Fig. 11. Farinograms of Reward and Ceres wheat flours.

recorded in Figures 12 and 13. The angle of the F/E ratio line was for instance 13° for Ceres and 27° for Reward when the doughs were mixed $3\frac{1}{2}$ minutes in the farinograph mixer.

So far, the cases were quite normal and certain characteristics of the farinograph curve could well be explained in terms of mixing sensitivity and general flour strength. We shall discuss now some types

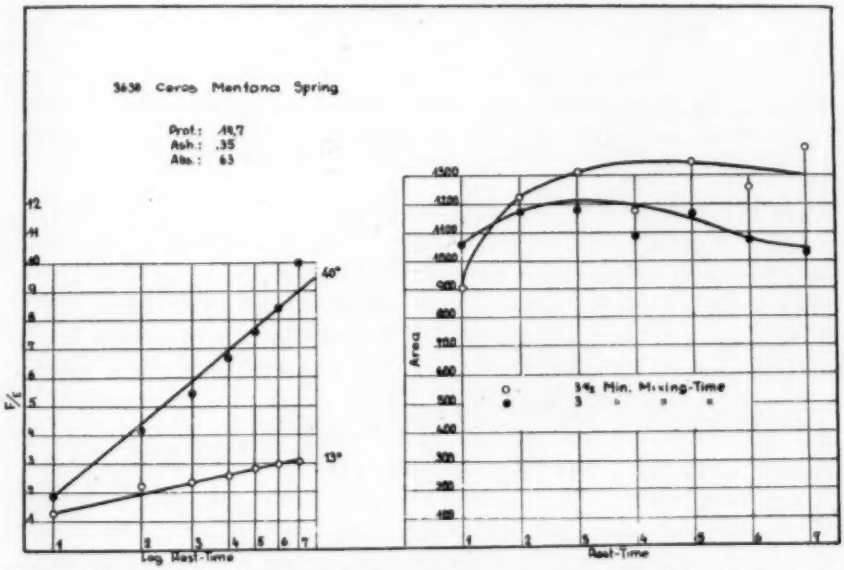

Fig. 12. Changes in F/E relationships of extensograms plotted against the logarithm of resting time of doughs made from Ceres wheat and areas under extensograms of doughs on resting.

which at the first moment could be misinterpreted from their farinograph curves.

The Montana winter wheat flour shown in Figure 8 seems to be of normal medium-strong type, if one considers the shape of the curve.

The relatively small curve width is abnormal, however, and together with the relatively high water absorption indicates stickiness of dough. Actually careful observation of the dough itself during the process of mixing disclosed a sticky condition. Still one might expect a medium-large loaf volume on baking it, and an extensogram of equivalent area, especially if its protein content of 12.6% is considered. The extenso-

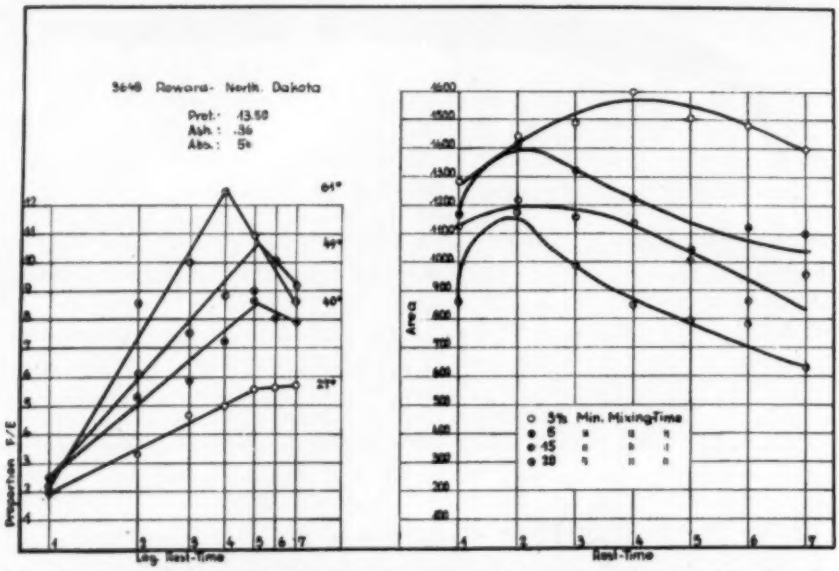

Fig. 13. Changes in F/E relationships of extensograms plotted against the logarithm of resting time of doughs made from Reward wheat and areas under extensograms of doughs on resting.

gram was medium to small in area, however, as shown in Figure 14, reaching a maximum of only 730 units. The F/E ratio was very small, and its rate of change with time of rest (plotted as the logarithm) was likewise small, smaller in fact than typical Kansas hard winter wheat flour doughs. The loaf volumes indicate that small changes in the dough structure occurred when the dough was mixed for widely varying intervals of time. Apparently the flour contains an unusually large proportion of substances that hydrate readily, render the dough smeary and sticky, and may even prevent the formation of a normal gluten reticulum. While a narrow farinogram and relatively high absorption give some indications as to the nature of such a flour, they do not afford a basis for an accurate prediction of the baking value. Since baking test and extensograph values coincide, it must be concluded that the effect of such overhydrated substances is more severe in resting doughs than in doughs during kneading.

At times wheat varieties have been tested (especially some Canadian wheats) which gave very strong farinograms, but baked well only after

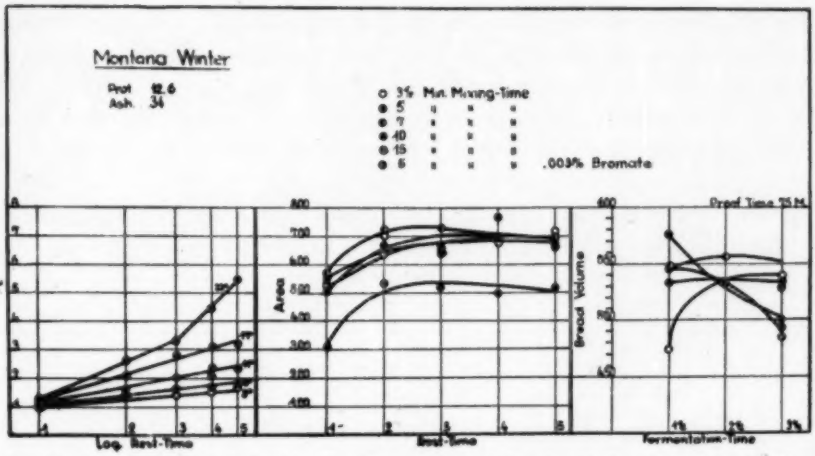

Fig. 14. Changes in *F/E* relationships of extensograms plotted against the logarithm of resting time of doughs made from Montana winter wheat; areas under extensograms of doughs on resting; loaf volume in cc. of bread baked from doughs fermented for varying time intervals.

being given a certain oxidation treatment. Resting doughs show a large extensibility and little resistance to extension. This is another case where it seems that some substances, very likely of fat-like nature, may orient themselves between gluten interfaces of doughs at rest. In the oxidized state they seem to lose their potency. The similarity of this type of dough and that prepared from Montana winter lies in the fact that both give stronger farinograms than are anticipated by the baking behavior of the untreated flour; the difference is that the Montana winter type is not improved considerably by oxidizing agents, while the other reacts very strongly. When deductions are made from the farinogram, it therefore must be kept in mind that secondary effects not registered in "excited" doughs may be of predominant influence in resting doughs and actual baking behavior.

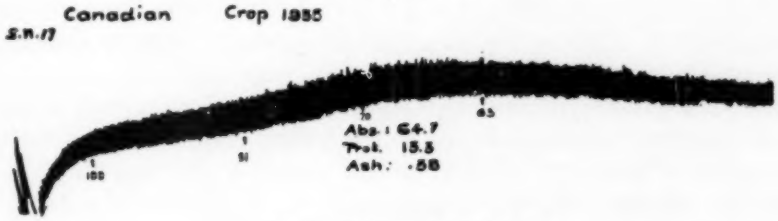

Fig. 15. Farinogram of *GM17*.

We have demonstrated that a tight gluten structure is registered in the farinogram by a rapidly rising initial curve. If gluten coagulation proceeds still further, one sometimes obtains curves of a general nature as shown by *GM17* in Figure 15. At first it appears to indicate a gluten character of pliable and normal elastic behavior, being only different

from that type of curve by the small curve width. The extensogram revealed an extremely tough dough, very sensitive to mixing (Fig. 16). The behavior in the dough mixer might be explained as follows: The coagulation of the gluten proceeded to such an extent that the rate of water absorption of the gluten was retarded considerably beyond the water-absorption rate of normal flours, resulting in a slowly rising curve. On standing, however, the water was bound tighter and the gluten became tough. Slack doughs and little mixing result in a comparatively normal dough with such a flour.

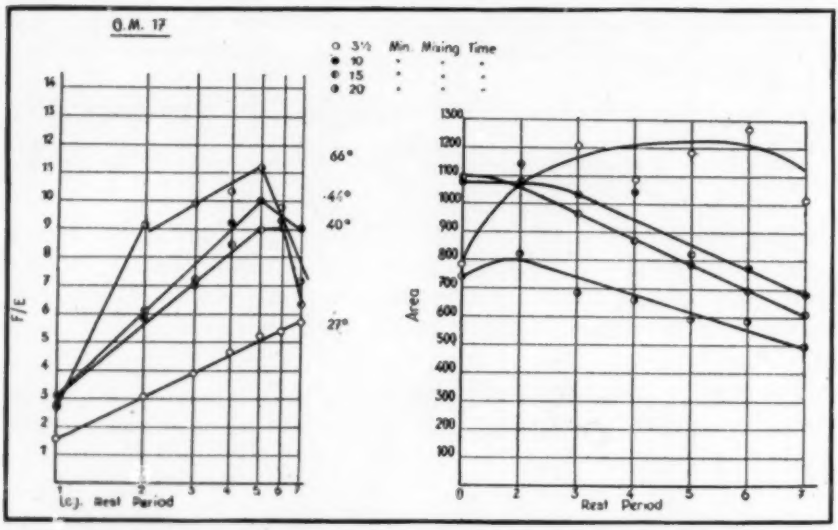

Fig. 16. Changes in *F/E* relationships of extensograms plotted against the logarithm of resting time of doughs made from *GM17* wheat and areas under extensograms of doughs on resting.

All these observations lead to the following general conclusions as far as deductions of mixing sensitivity from farinograms are concerned: Flours which yield farinograms that are similar except in the initial stages of mixing exhibit differences in sensitivity to overmixing. Flours represented by curve type *A* at the left in Figure 17 will be more sensitive than type *B*. If the fermentation period of the resulting dough is very short ("no-time dough") flour *B* will require a longer mixing treatment than type *A*.

Flours which yield farinograms differing primarily in the *width* of the beginning portion of the curve will vary in sensitivity to overmixing, in the direction of increased sensitivity for the flours having the narrower farinograms (right-hand picture of Fig. 17).

Flours of similar general class (for instance the southwestern hard winter class), differing however in strength as indicated in Figure 18

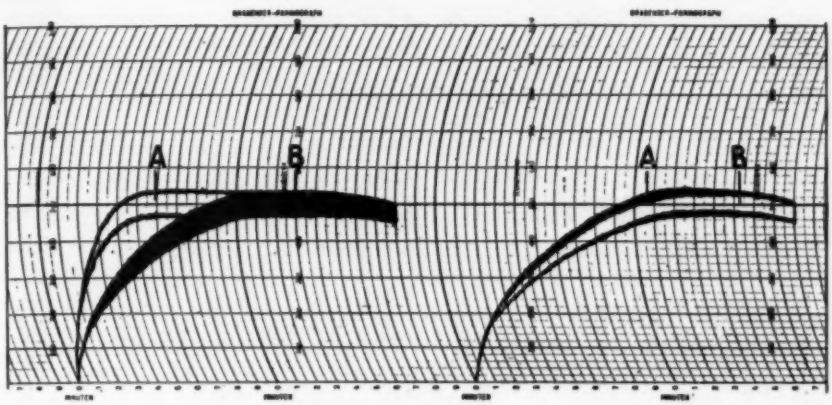

Fig. 17. Schematic farinograms, differing in the initial part of the curve (*A* and *B* at left) and in curve width (*A* and *B* at right).

(*I*), show decreasing mixing sensitivity in the direction of increasing strength, using developing time as a criterion for strength. The difference between curves *A* and *B* of Figure 18 (*I*) actually represents

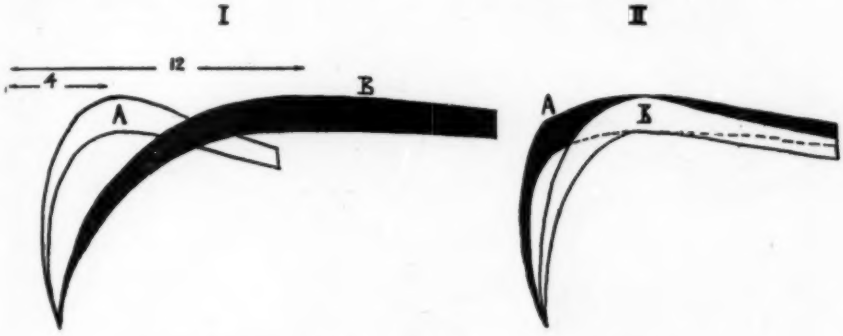

Fig. 18. Character of farinogram as influenced by state of oxidation.

the range of strength observed in the hard winter wheat class of medium-protein level. Under prevailing commercial conditions in the bakery trade the zone where damage by overmixing might be observed is probably restricted to flours of a strength rating of less than six minutes of developing time.

Flours differing in farinogram character as indicated by curves *A* and *B* in Figure 18 (*II*) show differences in mixing sensitivity depending upon the state of oxidation of flour or dough. Usually type *A* will be more sensitive. Type *B* will show a higher capability for dough recovery on standing. Dough recovery is an important factor in appraising American bread flours. A flour which gives a "weaker" farinogram in the sense of a higher "degree of softening" should not

be considered as being more "mixing sensitive," because the rate and magnitude of the subsequent recovery might prove the reverse in many cases. These deductions do not apply in the full sense when "secondary effects" exert a predominant influence.

Change of Dough Extensibility Effected by Molding

Practical baking experience has indicated that certain types of "bucky" doughs made with strong northwestern wheat flours are more sensitive to molding manipulations than characteristic southwestern hard wheat flours. To determine the occasion for this, as revealed by extensograph measurements, the following studies were undertaken.

Two flours were available for this purpose, a strong Manitoba which yielded a "bucky" dough and a medium-strength Bahia Blanca flour milled from Argentine wheat. In consequence of preliminary observations of these doughs, a schedule of two treatments was laid out which involved (*a*) molding every hour, and (*b*) molding only once, one hour before measuring, in the instance of both flours. The results, taken from the extensograms and recorded graphically in Figure 19, show

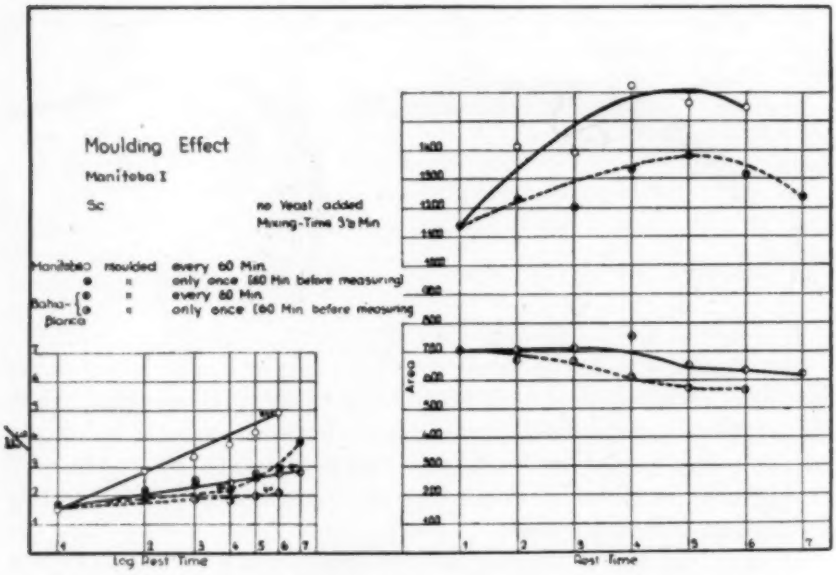

Fig. 19. Changes in F/E relationships of extensograms plotted against the logarithm of resting time of doughs made from Manitoba and Bahia Blanca wheat and areas under extensograms of doughs on resting.

that the tougher Manitoba flour dough responded much more to the repeated molding than did the more pliable Bahia Blanca dough. Thus the actual increase in the area of the farinogram effected by

molding treatment was twice as large with the Manitoba as with the Bahia Blanca. Likewise, the slope of the F/E curve plotted against time was greater with the former than with the latter, the values being 22° and 5° respectively.

These extensograms accordingly confirm practical shop experience, since the general practices in baking bucky doughs has been to punch very little and to operate the molder with the sheeting rolls set as far apart as possible in order to secure the best quality of bread. This fact may have some bearing on the methods followed in testing flour with the extensograph. Thus in ordinary bake-shop practice doughs are often punched lightly only once or twice, which is less rigorous than is accorded by the present extensograph "make-up" or rounding and molding apparatus. Differences might become apparent on the extensograms, therefore, which would not appear in the bakery.

To test this assumption further, five flours of rather widely varying strength were tested in two manners, involving (*a*) molding the dough repeatedly at hourly intervals and testing as heretofore in the extensograph (this being described in Figure 20 as "normal method") and (*b*)

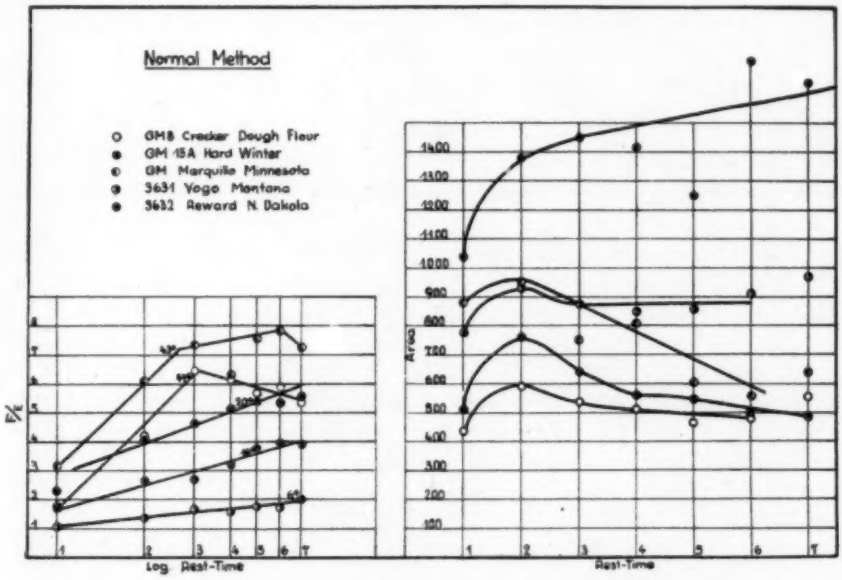

Fig. 20. Effect of repeatedly molding doughs at hourly intervals upon the F/E ratio and area of extensograms.

dividing the dough from the farinograph into three portions of 150 g. each, molding one piece immediately, the second piece after one hour, the third piece after two hours, and then testing each piece one hour after it was molded. This procedure yielded the extensograph data

recorded graphically in Figure 21. Since with both methods the different flours were rated in the same order, as is apparent from the graphs, we consider the "normal method" the more suitable one. It has the advantage that one is able to make duplicate determinations at every hour and can continue the tests for as many hours as one finds this to be necessary.

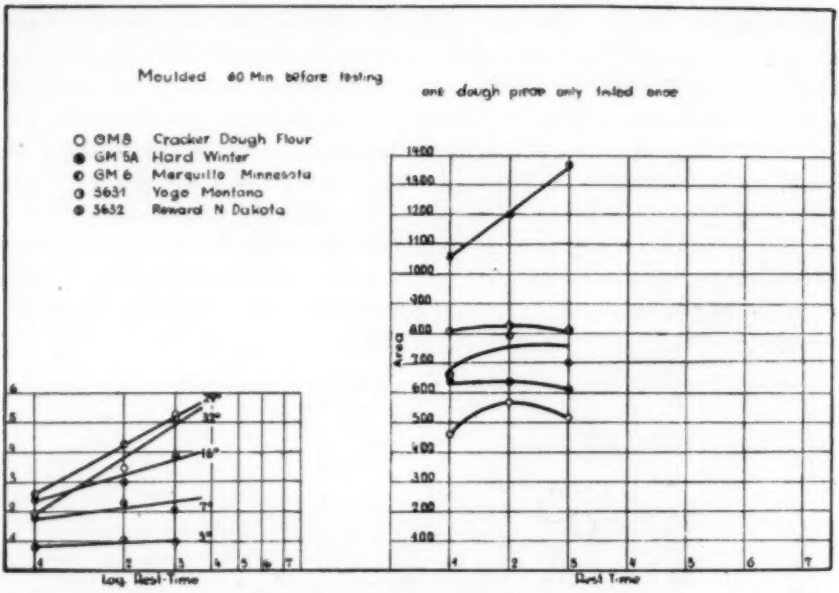

Fig. 21. Effect of molding each piece once after mixing, after one hour of fermentation, and after two hours of fermentation and then testing with the extensograph one hour thereafter, namely one, two, and three hours after mixing respectively.

Summary

Dough properties change steadily with time and as a function of mixing, fermentation, and other treatments. It appears important, therefore, to study the rate and direction of these changes rather than to measure dough properties at one stage only.

Dough plasticity as a function of mixing treatment is a significant characteristic, but it fails to disclose other important actual or potential properties such as are effected for example by certain chemical treatments. It is not always possible to predict, from such measurements made during the initial mixing, how far a dough may recover its properties after severe overmixing.

Extensibility measurements, such as can be made with the extensograph described in this paper, give useful supplementary information in such instances.

Vigorous treatments such as are accorded by mixing, molding, and punching, effect an "excited condition" in a dough (work hardening), in which condition it exhibits different physical properties from those shown in a state of relaxation. These induced effects do not remain constant, and the dough tends to return to its original state if allowed to stand undisturbed for a time, and the rate and degree of change depend upon the properties of the flour and the treatments to which it, or the dough, has been previously submitted.

On extended overmixing, doughs tend to lose extensibility (E) and to increase in resistance to extension (F) on standing. This may be analogous to the reversible thixotropic behavior observed in certain simple gels. In general those flours which evidence the greatest sensitivity to overmixing in the dough stage also exhibit the greatest tendency to recover the properties of a normally mixed dough.

Successive extensograph tests conducted on one dough aliquot after varying rest periods gave essentially the same relative results for different flour doughs as tests conducted on separate aliquots for each rest period.

While the ideal procedure in measuring mixing sensitivity with the extensograph is to accord various mixing treatments to a series of doughs prepared from the same flour and then observe the progressive changes in properties with time, the general class of flour into which most American bread flours fit can be recognized, usually, from the farinograms. Accordingly, the latter can be employed as a basis of classification in such instances, even though the farinograms do not tell the entire story.

"Optimal mixing time" must be regarded as a relative term, depending upon such factors as the type of mixer employed, nature of fermentation, and chemical treatment accorded the dough. It is not a definite or absolute value, except as thus qualified.

American bread flours are, in general, not highly sensitive to mixing treatments, although borderline cases must be recognized, and several such types have been discussed which can be identified by their farinograms and extensograms.

Two types of flours which yield doughs responsive to molding treatment (*a*) the "bucky," overelastic dough and (*b*) the "dead" type of dough which is notably deficient in elasticity, may be distinguished by the area and shape (F/E ratio) of the extensograms. Strong flours from hard wheats respond more positively to vigorous punching treatment such as is accorded by the make-up machines of the mechanized bakery, or by the dough-forming appliances of the extensograph, than doughs made from softer wheats.

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REVIEW OF PROGRESS IN RESEARCH ON BREAD STALING

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The loss due to staling of bread is a serious burden to bakers generally and the economics of bread staling have been discussed by many authors. Almost every baker is aware of the economic side of this problem. Accordingly, the economics of bread staling will be dismissed and the scientific side of the problem considered.

From the technical standpoint losses due to stales can be reduced by producing bread of high quality and long keeping quality, *i.e.*, by keeping bread fresh from time of production to time of consumption. It is probable that all great developments in the future in retarding bread staling will be due to exacting scientific investigation. Scattered practical experiments will help but will do little to clarify this vast complex problem. A great deal of research has already been performed in this field; however, in comparison to what needs to be done, research is only in its beginning.

Changes that Take Place during Bread Staling

Bread staling processes can be divided into: (1) staling of the crust, and (2) staling of the crumb. The staling of the crust is quite different from the staling of the crumb of the bread. The dry crisp crust of fresh bread becomes soft and leathery as bread stales. The baker increases the rate of staling of the crust by wrapping bread in "moisture-proof" paper. However, this is necessary in order to keep the bread in a sanitary condition.

The process of crust staling is quite easily understood. When fresh bread comes out of the oven the crust is dry and brittle, and as bread ages the moisture from the center of the loaf penetrates to the crust, making it soft and leathery. When bread is wrapped in "moisture-proof" paper, evaporation of moisture from the crust is stopped almost entirely and thus it takes up the moisture from the center of

the loaf, is unable to lose it to the surrounding atmosphere, and becomes soft and leathery more quickly than if it were not wrapped. Unwrapped bread crust will become stale by the same process when the atmosphere is very humid. If the humidity is great enough, the crust may even take up moisture from the air.

Alsberg (1936) defines crumb staleness as ". . . the change in flavor and texture that develops in time." He considers the word flavor to involve both taste and smell. The texture becomes harder, tougher, and more crumbly as bread stales. The staling of the crumb is a very complex process. Besides the changes mentioned above, the crumb loses its water. However, the above changes (becoming hard and crumbly) occur before the crumb has lost much of its water. Alsberg summarizes the order of these processes as follows: ". . . first it becomes tougher and harder, next it becomes crumbly, and finally after a much longer time it dries out."

Besides all of these changes, the crumb loses some of its power to swell when placed in water. The crumb of fresh bread swells more than stale bread. This phenomenon was first reported by Lehmann (1894). Also, Lindet (1902) has pointed out that the amount of soluble starch decreases as bread stales. This refers to the amount of starch in the bread that is soluble in water.

These changes on staling occur with whole-wheat and rye bread, as well as with white bread, but to a smaller degree (Katz, 1935). Katz (1928) has stated that they do not occur in baked products of low moisture content, such as zwieback. Breads with little or no starch, such as gluten bread, show these changes only slightly (Katz, 1935).

Summarizing the changes that take place as bread stales, we have: (1) crust becomes soft and leathery, (2) crumb becomes tough and hard, (3) crumb becomes crumbly, (4) crumb loses power to swell in water, (5) amount of soluble starch in crumb decreases, and (6) crumb dries out (*i.e.*, loss of water by evaporation).

An approximate chemical analysis shows little appreciable difference between fresh and stale bread (Cathcart, 1938). Karacsonyi (1928) found that the acidity either remains constant or shows some decrease as bread stales. However, Barnard and Bishop (1914) found that acidity of perfectly stale bread can increase during further keeping, due to the activity of microörganisms. There also are indications of changes in the composition of the fat in very old bread.

Theory of Crumb Staling

The first ideas of bread crumb staling were that it was due entirely to the loss of moisture. However, as early as 1852 Boussingault

(1874) showed that bread would stale when kept in a container where it cannot lose any moisture. Boussingault then took the bread which had staled without losing any water and made it fresh by heating at 60°C. or higher.

Von Bibra (1861) confirmed Boussingault's findings and extended his observations to include rye bread. Von Bibra also showed that bread containing less than 30% moisture could not be freshened by heating unless it was moistened first. Alsberg (1936) states, "In this connection, it is perhaps significant that native wheat-starch granules when fully hydrated contain about 30% (according to Rodewald, 36%) of water of hydration."

Von Bibra suggests that the moisture in fresh bread is mainly in an uncombined state; however, on staling it enters into chemical combination. Heating supposedly reverses the process and sets the water free; thus the bread is returned to its fresh form if sufficient water is present.

Horsford (1876) suggested an explanation of the process that occurs during staling. He explained that the gluten is dehydrated during baking, while the starch retains most of the water. Thus, during aging the gluten takes up water from the starch. This leaves horny, hard starch particles and accounts for hardness and crumbliness that develop during staling. On reheating the water passes back to the starch from the gluten and the process can be repeated innumerable times.

Boutroux (1897) assumed that the hard, horny starch which is left after the loss of water to the gluten is "a derivative of starch." Lindet (1902) suggested that this "derivative of starch" was simply a less soluble form of starch produced from the starch of fresh bread.[1] This change in form of starch is called retrogradation [2] (the use of this term is questioned by some workers) of the starch and is accompanied by the setting free of moisture to the other components of the loaf because of this change and not because the gluten takes the moisture away from it. This process is more rapid than the development of crumbliness. Katz (1928) explains the delay in the development of crumbliness by assuming that it takes time for water to diffuse from the starch to the protein and of course crumbliness is not noticeable until this diffusion has taken place. This delay in the onset of crumbliness is verified by microscopic examination (Verschaffelt and van Teutem, 1915).

Ostwald (1915) reports that the starch gel of fresh bread [3] is like

[1] Alsberg (1936) points out that the soluble starch of fresh bread is β-amylose.

[2] Lindet called the process retrogradation because he found that the amount of soluble starch decreased as bread staled. However, Lindet also concluded that the gelatinized starch granules imbibe less and less water as the bread stales.

[3] Only first-degree gelatinization.

other gels and that the staling process is simply due to syneresis, *i.e.*, extrusion of water. Some object to this on the basis "that a gel as concentrated as first-degree gelatinized starch does not extrude water."

Katz (1928) has followed the process of staling by the following methods: (1) increase in crumbliness and hardness, (2) decrease in swelling of crumb in water, (3) decrease in amount of soluble starch, and (4) change in X-ray pattern.

On the basis of his results, Katz has explained bread staling as follows: There is a physico-chemical equilibrium set up between the fresh state and stale state. At temperatures of from 60°C. up, the fresh state is the stable form. Thus at temperatures above 60°C.[4] bread will freshen up. At temperatures below 50°C. bread will stale and the lower the temperature the faster it will stale. The maximum rate of staling occurs at about −3°C. By lowering the temperature below this point the rate is decreased again because the bread freezes solid (all reactions are retarded in the solid state). Katz states that at about −193°C. bread will remain fresh indefinitely.

Katz (1928) has shown that the changes which take place in bread staling are very similar to those that take place in a starch gel on standing, and by X-ray studies he has shown that there was the same change in the starch in both cases. Because of this and the fact that bread contains many times (about five or six times) as much starch as protein, the changes in the starch can be taken as the same changes that take place in the staling of bread.

After further work, Katz (1930) modified the above view and states that the process is much more complex and involves a heterogeneous equilibrium. Recent work with X-ray diagrams indicates that in fresh bread the starch exists in an amorphous and crystalline form, while in stale bread it exists totally in a crystalline form (Katz, 1937).

Alsberg (1936) has pointed out that it is possible to explain the changes that take place when bread stales without assuming any chemical change in the starch, any difference between a starch gel and other colloid gels, or without being inconsistent with the known facts of retrogradation. According to Alsberg the staling process is simply an expected physical change of the starch-gluten complex involving the loss of water from both the starch and gluten. He shows that there is no reason to expect the gluten to take up moisture from the starch during the process.

Kuhlmann and Golossowa (1936) have shown that the water-binding capacity of bread crumb gradually decreases during staling and that the water-binding capacity of bread and dough depends upon the method of bread making.

[4] C. H. F. Fuller (1938) finds that bread stales slowly at 60°C. There is definitely a tightening of the crumb at 60° to 100°C., he states.

After reviewing the theories and data (with additional data of his own) of the above authors, Fuller (1938) suggests that during staling gelatinized starch undergoes a reduction in hydration capacity (Kuhlmann and Golossowa, 1936) and an alteration of the proportion of α- and β-amylose. Fuller explains that there appears to be a definite equilibrium between α- and β-amylose at any one temperature. He points out that staling can be affected by keeping the proportion of α- and β-amylose shifted toward the fresh state or by changing the state of hydration of the starch. Heat alters the former, he says; freezing and sugars, the latter.

These are all very important considerations, for, as Alsberg points out, if this change in bread on staling involves a chemical equilibrium it should be possible to find a catalyst which would shift the equilibrium so that staling would not take place at room temperature. If it is not a chemical equilibrium then there is no need to spend time and money searching for a substance (catalyst) that will prevent staling. *Thus, it is evident that it is necessary first to determine the nature of the staling process before looking for substances that will prevent it.* Moreover, it is evident that this theoretical research is of great practical importance. Certain important facts have been established. Much more is to be learned.

Methods of Measuring Rate of Staling of the Crumb

The methods of measuring staleness have been enumerated by various writers; Alsberg (1936) and Hutchinson (1936) have summarized the methods. They will be extended and summarized here and those which have met with greatest favor given in detail.

Crumbliness of the crumb.—Crumbliness cannot be measured accurately. The only method to determine crumbliness is by use of the finger.

Hardness or compressibility of the crumb.—Hardness or compressibility of the crumb can be measured quite accurately. This is a method which the baker or bakery technician could very well use in his shop. Methods of measuring compressibility have been described by Bailey (1930), Katz (1917b, 1928, 1934a), and Platt (1930). All of these pieces of apparatus operate on the same principle. An apparatus constructed according to Platt's ideas and used here at the Institute is shown in Figure 1. The apparatus is essentially a large balance with a plunger (*A*) attached to underside of the right-hand pan. A uniform piece of bread crumb (1½ inches thick) is placed on the disk (*B*). A weight (about 200 g.) is placed on the right pan and a chain weighing exactly the same on the left pan. A 2-gram weight is then added to the right pan; this is just enough extra weight to hold the

plunger down lightly on the bread and steady the pointer (*C*) so that an initial reading can be taken on the scale (*D*). Then the chain is removed slowly by means of a string run over a pulley, suspended overhead, and then attached to a windlass (*E*) equipped with a crank. Sixty seconds after beginning to remove the chain a second reading is taken. The difference between the two readings gives the compressibility of the crumb. In this way compressibility readings can be made as the bread ages. It might be emphasized that as the bread

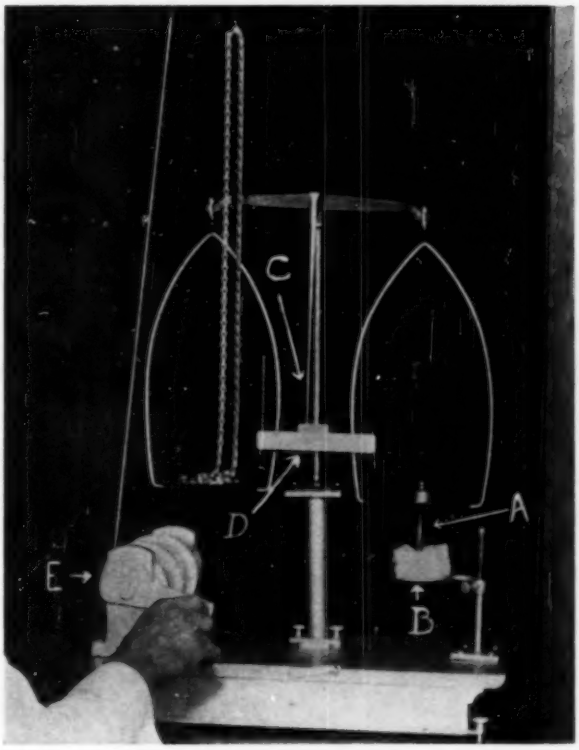

Fig. 1. Apparatus for measuring the compressibility of the crumb of bread.

grows harder the compressibility readings become less. Temperature has considerable effect on these readings so that it should be kept constant over a series of measurements (Platt, 1930).

Swelling of crumb in water.—Based on observations of Balland, Lindet, Lehmann and others, Katz (1917b, 1928) has used the following method, based on the swelling of crumb in water, for measuring staleness.

"Ten grams of bread crumb, together with an excess of water, are passed through fine bolting cloth (80 mesh per centimeter). The

volume of the liquid (which is saturated with toluene in order to prevent fermentation) is raised to 250 cc. capacity. After 24 hours the volume of the decantate or deposit is read off. Upon shaking again, another 24 hours is allowed for settling, a second reading made, and the mean of the two readings taken. The volume of the decantate is shown to be considerably larger for fresh bread than for stale bread, for instance 52 cc. compared with 34 cc."

Cathcart and Luber (1939a) have found that it is much easier to put the bread crumb through a brass-frame, 200-mesh sieve of 5 inches

Fig. 2. Showing how bread crumb is rubbed through sieve. Apparatus, left to right: 250-cc. graduated cylinder, 30-cc. centrifuge tube, 2-liter beaker, sieve on beaker, wash bottle.

in diameter, than the bolting cloth. The sieve has the additional advantage of fitting snugly on top of a 2-liter pyrex beaker, which serves to catch the washings. The apparatus needed is shown in Figure 2. The crumb is rubbed through with the forefinger and the second finger (Fig. 2). A typical example of the difference in the amount of sediment between fresh and stale bread is shown in Figure 3—35 cc. for stale bread and 48 cc. for fresh bread. This test can be applied in the bakery. For rate of staling curves by this method, see Cathcart and Luber (1939a).

This method has been modified still further by Cathcart and Luber. Simply, instead of waiting on the sediment to settle for 24 hours, 30 cc. of the sediment suspension is transferred to a centrifuge tube (see Fig. 2) and centrifuged for 2 minutes. The results in cubic centimeters of sediment are read off directly. A typical example of the difference between fresh and stale bread is shown in Figure 4. The difference is less here than with the graduate cylinders because less of the sediment suspension is used. For rate of staling curves by this method see Cathcart and Luber (1939a).

Fig. 3. Showing difference in sediment between fresh and stale bread in graduated cylinders.

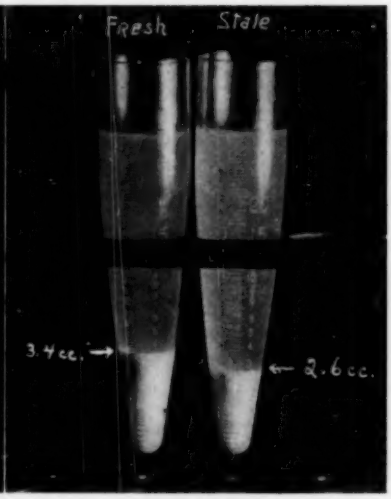

Fig. 4. Showing difference in sediment between fresh and stale bread in centrifuge tubes.

Karacsonyi (1929) has also modified the above method. Instead of letting the sediment suspension stand 24 hours he measures the viscosity of it. It is reported that as the bread ages the viscosity decreases.

Fuller (1938) has modified this method as follows: he determines the amount of water to give a standard consistency in a farinograph with a definite amount of shredded bread crumb. The main objection is that bread made with diastatic malt extract or a similar substance gives low values (about the same as stale bread) when fresh and the values fail to decrease on staling. Fuller did find, however, that starch gels showed a decrease as did bread (except that made with diastatic malt), which agrees with the results of Katz's X-ray studies, that the starch is the important component involved when bread stales.

Amount of soluble starch.—This method is complex and time-consuming. However, it is interesting to know that such a method exists

and that the amount of soluble starch decreases as bread stales. Katz (1928) describes the method in detail and considers this method less satisfactory than the one based on the swelling of the crumb in water (Katz, 1917a, 1928).

Opaqueness of crumb.—Glabau and Goldman (1938) have found that the starch gel of bread becomes more opaque as the bread ages. By means of a photoelectric cell "set-up" the light that passed through the bread under definite conditions was measured. The change in opaqueness parallels the change in crumbliness. This method of measuring staleness is not a modification of the "swelling of crumb in water" method; however, both are undoubtedly due to the same change in the starch.

X-ray pattern.—X-ray studies of bread have been made, notably by Katz (1928, 1930, 1937). Although X-ray does not offer a method of following the rate of staling, it has definitely shown, as mentioned above, that the starch is in a different form in stale bread than it is in the fresh product. Thus, from a technical standpoint staling is simply due to this change in the starch. This change in the form of starch seems to account for the decrease in compressibility of the crumb, decrease in the swelling of the crumb in water, and decrease in amount of soluble starch.

Loss of water by evaporation.—The loss of water by evaporation has been mentioned above as the last step in the staling process and can be accurately measured by laboratory methods. However, as pointed out above it does not bear much relationship to the changes in the starch, since the change in the starch will take place even if evaporation is prevented. Nevertheless, in commercial practice today, the loss of moisture is of the utmost importance. For further consideration of this factor, please see page 116, "Physical Methods vs. Human Beings for Determining Staleness."

Retarding the Staling of the Crust

Crust staling can be prevented by proper storage methods. When bread is wrapped (crumb at approximately 85°F.) moisture passes from the inside crumb to the crust. Thus the crust becomes soft, for it cannot lose water to its surroundings because of the moisture-proof wrapper. In general, any method of preventing the crumb from losing water increases the staling of the crust. Crust staling can be prevented by storage in a moderately dry place after adequate cooling.

Katz has patented a process[5] for preventing crust staling. This consists mainly of a chamber in which unwrapped bread can be kept

[5] This process was used to a small extent in Holland to keep bread over night.

in a circulating atmosphere of from 65% to 70% relative humidity. The upper limit prevents the crust from taking up water and the lower limit prevents the bread from drying out too rapidly.

If bread were allowed to dry out more than is the usual custom before it is wrapped, the crust would keep better; however, this would cause the crumb to be more dry than is desirable. Thus, the crust is sacrificed for the crumb.

Barnard and Bishop (1914) have shown that if bread is allowed to cool in a fairly dry atmosphere and storage temperature before wrapping, the crust does not absorb water from the crumb. They believe that most of the fault comes from wrapping the bread too warm. The modern rapid cooling methods offer means of cooling bread to the proper temperature without an excessive loss of moisture. This subject has been gone into quite thoroughly by Berg (1926).

Hutchinson (1936) lists the following as the chief factors in the production of crisp crust of long life: (1) flour type, (2) fermentation procedure, (3) method, time, temperature of baking, and (4) storage conditions. He points out that very little is known about the first two, and that the last two are the most important. In regard to the third point Hutchinson says: "Undoubtedly well-baked crusty bread does seem to stale *in the crust* more rapidly than unburnt crust, and the leathery tough nature of most crusts seems to be due to the method of production of the crust quite as much as to storage conditions." Steam in the oven is cited as an example of the latter. That is, the crust of bread baked in an oven with steam frequently becomes very tough as compared to that baked without steam. The one with steam, however, has a much better crust color and bloom.

Alsberg (1936) considers that the following will produce a crust that will remain crisp for a long time: (1) high fermentation temperature, (2) a high proportion of yeast, (3) as little water as practicable in dough, and (4) small amount of salt. From the next section it will be noted that none of these factors is beneficial as far as crumb staling is concerned.

Shortening has a beneficial effect on the crust. Hutchinson states, "It is known that the influence of shortening agents upon the crust is very marked, frequently yielding crust of improved palatableness, crispness, and general attractiveness."

These factors which affect the crust are summarized briefly in Table I.

Retarding the Staling of the Crumb

The crumb staling process may be retarded by various methods. The methods which demand attention are heat, refrigeration, wrap-

TABLE I

EFFECT OF VARIOUS FACTORS ON THE RATE OF STALING OF BREAD CRUST

Factors which affect crust staling	Effect on rate of crust staling	Reported by
Flour type	Best type not determined	Hutchinson
Fermentation procedure	Best procedure not determined	Hutchinson
Method of baking	Best method not reported	Hutchinson
Time of baking on short side	Decreases rate	Hutchinson
Temperature of baking	Best temp. not reported	Hutchinson
Steam in oven	Increases rate	Generally known and Hutchinson
High fermentation temperature	Decreases rate	Alsberg
High amount of yeast	Decreases rate	Alsberg
Little water as practicable in dough	Decreases rate	Alsberg
Small amount of salt	Decreases rate	Alsberg
Shortening	Decreases rate	Hutchinson
Moderately dry storage	Decreases rate	Katz
Wrapping	Increases rate	Generally known
Proper wrapping	Neither increases nor decreases rate	Barnard and Bishop

ping, ingredients, and methods of manufacture. The baking industry is fairly well agreed that certain methods of manufacture, etc. (see below) will prolong the life of bread. Katz (1917a) and Alsberg(1936) state that the test for staling based on the swelling of the crumb in water does not show that any of these procedures of manufacture delay the aging of the starch granules of the crumb. Not enough work has been done on the method based on the compressibility of the crumb or others to draw conclusions as to how results from them compare with the swelling-power method. Steller and Bailey (1938) found that the compressibility and viscosity methods (noted under method based on swelling of crumb in water above) gave results that were more consistent and uniform than the data obtained by swelling of the crumb in water. They also point out that the latter method is not sensitive to minor changes in the condition of the bread. The writer has found that this property is also true in regard to temperature of the bread and room. Thus, in this respect, the latter method is more desirable, for variations in temperature will cause less variation in the results obtained.

As Alsberg (1936) has pointed out, "It cannot be doubted that some of these practical procedures do have the effect claimed for them." The explanation probably is that the method based on the swelling of crumb in water tells the state of the starch but that there are other things that must be taken into consideration. For example, shortening is known to lengthen the life of bread. This is not due to the delay in the changes in the starch but probably to the way it masks the effects of these changes.

The following are various methods of prolonging the life of the crumb of bread:

Heat.—The reheating of bread to freshen it has been known for a long time. The experiments of Boussingault (1874) have been mentioned before. Katz (1928) and others have done a great deal of work on this method. It can be concluded that holding bread at 60°C. or more will maintain it in a fresh condition. Many investigators consider that bread will remain fresh indefinitely at 60°C.; however, Fuller (1938) has reported that staling occurs slowly even at this temperature. The chief objection to this procedure is that bacteria generally develop inside the crumb, producing a penetrating off-aroma. Katz states that this aroma is generally detectable after 12 to 24 hours. With addition of acid salts to bread, the heating method has been applied for periods of about 12 hours. It is important that ventilation and humidity be controlled so that the crust of the loaves will not become soft and leathery or become unduly dry. On the whole, this method does not seem to offer practical possibilities due to development of the penetrating off-aroma and due to the crusty flavor which is generally imparted to the crumb.

Refrigeration.—As pointed out before, the maximum rate of staling of bread occurs at about −3°C. However, as Katz (1928) and others report, temperatures of about −10°C. retard the staling process greatly. Alsberg (1936) even says that temperatures of from −10°C. to −20°C. prevent it altogether. Because of the many conflicting reports, and in order to determine just how long bread can be kept fresh at freezing temperatures, Cathcart and Luber (1939b) have investigated the problem. They have found that at temperatures of −22°C. bread can be maintained fresh for approximately 30 days according to scientific scoring methods (according to the swelling-power test it was practically stale in 24 hours) and at −35°C. for approximately 70 days. In the latter case it was also fairly fresh according to the changes in the starch. The bread was handled in a commercial manner throughout and the crust was kept in good condition by keeping the bread wrapped in moisture-proof wrappers during freezing and thawing. The method is very promising and might prove practical in helping the baker get bread to the consumer in a fresher condition. It would, of course, be of great help in emergencies. As a result of the development of refrigerated warehouses, it seems to be the most promising method of the future.

Wrapping.—Bread is wrapped to keep it in a sanitary condition and to minimize the drying out as much as possible. Wrapping delays staling only insofar as the loss of moisture is connected with staling. As pointed out above, the change in the starch takes place even though

the loss of moisture is prevented. Thus, the fact that a loaf of bread has not lost much of its moisture does not mean that it is fresh as far as the starch is concerned. Nevertheless, wrapping plays a considerable role as far as the consumer is concerned by decreasing drying-out and at the same time loss in weight. Thus, from this latter standpoint, wrapping increases the life of bread.

Wrapping so retards the loss of moisture that the usual hard, dry crumb just underneath the crust, which always becomes evident in 24 hours with unwrapped bread, never develops. As mentioned before it allows the moisture in bread to equalize itself between the interior crumb and the crust.

It is interesting to note that Platt (1930) found little difference between the compressibility of central crumb of wrapped and unwrapped bread on aging.

Morison and Gerber (1925) and also Barnard (1924) give the moisture content of unwrapped bread as it dries out in the ordinary atmosphere. There is a rapid fall in moisture content in the first 48 hours. Results by Cathcart and Pushnik (1939) on sliced, moisture-proof wrapped bread show that from the time of wrapping until the bread is 72 hours old, only about a 2% loss of moisture occurs.

Ingredients.—Hutchinson (1936) has divided substances that have been recommended for addition to bread dough to retard staling into two classes: (1) those that prevent or delay the change in the starch and (2) those that improve bread quality. Substances belonging to the first class would be of utmost commercial value. However, as Hutchinson and also Alsberg (1936) have stated, a substance which will do this without detracting from the good qualities of normal bread has not been found. It should be mentioned, however, that Katz (1917a, 1917b, 1928) found that aldehydes and alkaline bases would do it, but they have *undesirable* physiological effects and large quantities are required; thus are of no commercial value.

Substances belonging to the second class are those that help to give better bread from the beginning or act as moisture retainers. These substances offset the changes in the starch but only delay this change slightly if any at all. These substances may be listed as follows: flour (wheat and rye), yeast, milk, salt, gelatinized starch (scalded flours, dextrinized flours, dextrin, potato flours, etc.), shortening, malt extract, sour dough, protective colloids (agar agar, mayonnaise, lecithin, etc.), gelatin, glucose (corn sugar), glycerin, soy flour, whey, egg whites, etc.

All workers[6] agree that flour is very important and that a flour

[6] For references to Alsberg and Hutchinson in this and the following sections, see Alsberg (1936) and Hutchinson (1936).

containing a large amount of high-quality gluten, if properly fermented, will prolong the life of bread. Alsberg states that the degree of refining of flour seems to have some influence and that very fine grinding is unfavorable. It is important to remember as Hutchinson states that "the staling problem is at a minimum with the best possible loaf made from the best possible flour." Dearsley (1925) has stressed the advantage of good-quality gluten. Katz (1934b) has also pointed out the importance of using high-grade flour. Jago and Jago (1911) state that some flours, particularly those with a high percentage of protein, readily become somewhat dry and harsh.

Alsberg reports that 5% to 10% of rye flour will slightly retard staling. This agrees with the accepted fact that rye bread does not stale as rapidly as white bread. Figures 3 and 4 of Cathcart and Luber's article (1939a) illustrate this latter fact. The two top curves in each figure show the centrifuge modification of the swelling-of-crumb-in-water method. The bottom curves show the regular Katz swelling-of-the-crumb-in-water method. It will be noted that the curves of the figure for white bread show a faster lowering of the degree of swelling than the curves for rye bread.

Alsberg says that the use of "not too much yeast" is favorable. He reports that yeast quality is important; however, he says that different types of yeast have not yet been adequately investigated. Alsberg also reports that a normal amount of salt is favorable.

Both Alsberg and Hutchinson agree that milk, shortening, malt extract, and gelatinized starch are favorable. The use of milk has also been stressed by Davis and Eldred (1923) and the American Institute of Baking.[7] The work of Glabau and Goldman (1938) also indicates that milk is favorable. Katz (1934b) also says that shortening, milk, and not too much yeast, are favorable to long life.

Bailey (1932) found that potato flour, malt extract, sour dough, and agar agar had a slight beneficial effect in reducing hardness by compressibility. Mayonnaise and two vegetable lecithins had no effect. Hutchinson says that his own observations agree with those of Bailey and states that the reduction of hardness is "probably a case of softer loaves initially rather than a real retardation of hardness development." Bailey also tried dextrinized starch, various sugars,[8] a great variety of dairy products and calcium peroxide (increases absorption). None had effect on the compressibility or the degree-

[7] Annual report, 1924.

[8] In contrast to this A. G. Kul'man and E. P. Balasheva (Tekhnol. Protsessy i Kontrol Pishchevoi Ind., 175–198, 1938) state that sugars retard the rate of staling. Listing carbohydrates in order with the most effective first they gave maltose syrup, glucose syrup, dextrin, beet sugar, maltose, glucose, soluble starch, and potato flour. Soluble starch and potato flour gave bread which turned stale sooner than bread without any special addition. Also A. K. Epstein and B. R. Harris (Baker's Helper **64**: 347, 1935) have patented the use of arabinose to retard staling.

of-swelling-of-crumb test. Gelatinized starch was found to be favorable by Katz (1934b).

In addition to the above, Hutchinson says that it is believed that gelatin, glucose, and glycerin prevent staling by retaining moisture.[9] Glycerin is now generally discredited for this purpose. As long ago as 1911, Jago and Jago (1911) listed gelatinized starch, dextrin, boiled potatoes, and potato flour as keeping bread moist longer. Also Whymper (1919) listed glycerin, glucose, malt extract, scalded potatoes, and potato flour as moisture retainers. Hutchinson classed soy flour and whey as slightly favorable. Steller and Bailey (1938) have concluded that the use of 1½% of free-fat soy flour reduced the rate of staling (change in starch) of bread, yet from a review of their data one is forced to conclude that the effect is very slight. Kirkland (reported by Hutchinson) performed many experiments on some of the above-mentioned substances and his results agree favorably with the reports of Alsberg and Hutchinson.

Banfield (1938) states that egg whites (six egg whites to 14 lbs. of meal) in a dough from which brown bread is made will produce brown bread which will keep moist for 36 hours longer than ordinary brown loaves. Egg yolk which contains lecithin is stated as being an excellent stabilizer for unstable doughs, but its effect on staling is not mentioned. Banfield says that potato mash and rye flour added to white dough favor moist, good-keeping bread. Gelatinized starches, scalded flour, gelatin, and agar agar give only a false water absorption according to Banfield; although they can hold much water in the cold, they will break down in the oven.

Hutchinson stresses a point that is very important to remember. That is, "many of the substances recommended for prevention of rapid staling have some undesirable effect which may counterbalance any good effect on staling; thus glycerol delays fermentation, and underfermentation invariably leads to rapid staling of bread." Soy flour is another example pointed out by Hutchinson; no real gain results from using it, for in quantities above 1½% to 2% of the weight of the flour there is a reduction in loaf volume, a deterioration in texture, and the development of an undesirable crumb color. Many other substances belong to this class; that is, agar agar, casein, and the like. However, not all of the substances listed above belong to this class.

In general, bread from a rich formula is preferable; that is, has better keeping qualities from the practical standpoint than bread from a lean formula. Platt (1930) has shown that rich-formula bread has greater compressibility.

[9] Treatment of dough with infra-red rays (Baker's Helper 61: 533, 1934) is said to retard staling by increasing the moisture content.

Methods of manufacture.—Besides the factors mentioned above, which affect the rate of staling of bread, certain methods of manufacture are said to be favorable. The following are those to be considered: absorption, mixing, time and temperature of fermentation, type of fermentation, handling, baking, and cooling.

Hutchinson believes that a slack dough is favorable to a longer life of bread. Alsberg states that high-speed mixing will prolong the life of bread and Hutchinson adds that the dough should not be over- or undermixed. According to Alsberg and Katz (1934b) a long fermentation at low temperature is favorable. Underfermentation is one of the chief causes of poor keeping quality, Hutchinson writes. Of course the important thing is *proper* fermentation. Proper fermentation is probably of more improtance than any one other single factor with the exception of heat and refrigeration.

Sponge fermentation is preferable to straight-dough fermentation according to Alsberg. The long-sponge system is recommended in preference to the shorter straight-dough system by Kent-Jones (1927). Of course, sour-dough fermentation is advantageous as mentioned above. Hutchinson states that in his work short-time processes with ordinary bread-making flours frequently gave bread of better keeping quality than that made by long-straight and sponge-dough systems. The important factor seems to be the correct adjustment of fermentation period to the flour and other ingredients. Hutchinson states: "though many bakers believe that bread made with large quantities of yeast at relatively high dough temperatures has poor keeping quality, we cannot agree, though undoubtedly the risk of incorrect fermentation is considerably enhanced when very short processes, *e.g.*, at relatively high temperatures, are employed. At present, the most most important method of combating loss of keeping quality is to produce the best loaf of which really good flour is capable. To state that a certain method of fermentation gives bread of better keeping quality than another system is of little significance unless all of the conditions, type of flour, etc., be stressed, and those keeping qualities considered to be of primary importance, specified."

Both Alsberg and Hutchinson agree that the proper handling of a dough is important. One should be careful to punch at optimum time and not permit overmanipulation in machine-made doughs. Alsberg and Katz (1934b) state that baking should be carried out slowly in an oven that is not too hot; overbaking is to be avoided. Hutchinson stresses that one should be careful not to underbake bread. One would take these statements to mean that the important thing is proper baking; however, none of the above authors states just what

proper baking is. Katz stressed the art and skill that a baker must possess and its important part in producing a loaf of long life .

Alsberg says that the loaf should not lose too much moisture in cooling. He recommends rapid cooling, provided too much moisture is not lost by so doing. Alsberg summarizes the factors which prevent the aging of the crumb of the bread as follows:

"1. Anything that increases the water content seems to be favorable to long life. . . .
"2. Anything that hampers the mobility of moisture (prevents evaporation) in the cooled loaf perhaps prolongs life. . . .
"3. Anything that conceals the effects of aging of starch prolongs the loaf's life in that the loaf remains acceptable to the consumer. . . ."

All the factors listed and discussed under this heading are summarized in Table II.

Physical (Mechanical) Methods vs. Human Beings for Determining Staleness

There are two ways of measuring staleness: (1) the physical or mechanical means which were mentioned under "Methods of Measuring Rate of Staling of Bread Crumb" and (2) examination by human beings. The factor which greatly controls the opinion of human beings is the moisture content. And in general any one of the factors listed in Table II which increases the moisture content and favors its retention will increase the life of bread as far as human beings are concerned. From tests performed (Cathcart and Luber, 1939b) factors of freshness which human beings consider to be very important are not necessarily ones which the physical tests measure (*i.e.*, changes in the starch). Now which is of the more importance, physical tests or those by human beings?

This question might be answered simply by saying that tests by people are not scientific, while the mechanical tests are. And, since scientific tests are superior to unscientific human-being tests, the scientific tests are to be preferred. Both Platt (1930) and Alsberg (1936) have pointed out how unreliable such judgments of people may be. Thus, on the basis of tests by human beings "it is idle to speculate about the reasons why specific procedures or specific ingredients act as they do." Yet human consumers buy the bread.

The physical tests are important in that they give us definite numerical results, which are unbiased and fairly reproducible. Much time and effort have been spent in developing these physical tests; however, in general they show (on basis of work so far) that the

TABLE II

EFFECT OF VARIOUS FACTORS ON THE RATE OF STALING OF BREAD CRUMB

Factor	Effect on the: Rate of practical staling	Effect on the: Rate of change of starch	Reported by
Heat, 60° C.	Decreases rate	Decreases rate	Katz, others
Refrigeration, −22° C.	Decreases rate	Decreases rate	Cathcart and Luber
Refrigeration, −35° C.	Greatly decreases	Greatly decreases	Cathcart and Luber
Wrapping	Decreases rate	No effect	Boussingault, Katz, others
Flour (large % and high-quality gluten)	Decreases rate	No effect	Alsberg, Hutchinson, Katz, others
Rye flour (5%–10%)	Slightly decreases	Little effect	Alsberg, Banfield
Yeast	?	No effect	Alsberg
Milk	Decreases rate	No effect	Alsberg, Hutchinson, Katz, others
Normal % salt	Decreases rate	No effect	Alsberg
Gelatinized starch, etc.	Slightly decreases rate	No effect	Alsberg, Hutchinson, Bailey, Katz, Jago and Jago, Whymper
Shortening	Decreases rate	No effect	Alsberg, Hutchinson, Katz
Malt extract	Slightly decreases	No effect	Alsberg, Bailey, Hutchinson, Whymper
Sour dough	Slightly decreases	No effect	Bailey
Protective colloids	Slightly decreases	No effect	Bailey, Hutchinson
Gelatin	Slightly decreases	No effect	Hutchinson
Glucose	Slightly decreases	No effect	Hutchinson, Bailey, Whymper
Maltose and glucose syrup	Slightly decreases	No effect	Kul'man, Balasheva
Invert sugar	Slightly decreases	No effect	Bailey
Glycerin	Slightly decreases	No effect	Bailey, Whymper
Soy flour	Slightly decreases rate	Very slightly decreases rate	Hutchinson, Steller, Bailey
Whey	Slightly decreases	No effect	Hutchinson
Egg whites	Slightly decreases rate	Probably no effect	Banfield
Slack dough	Decreases rate	No effect	Hutchinson
Optimum high-speed mixing	Decreases rate	No effect	Alsberg, Hutchinson
Proper fermentation	Decreases rate	No effect	Alsberg, Hutchinson, Katz
Sponge fermentation	Decreases rate	No effect	Alsberg, Kent-Jones
Long fermentation	Decreases rate	No effect	Kent-Jones, Katz
Proper handling	Slightly decreases rate	No effect	Alsberg, Hutchinson, Katz
Proper baking	Slightly decreases rate	?	Alsberg, Hutchinson, Katz
Proper cooling	Decreases rate	No effect	Alsberg

crumb of bread is stale long before human beings think so. In general the two methods of measuring staling do not agree. This was pointed out above and is evident from Table II.

This does not mean that the physical tests are useless—far from it. They are the only reliable means that are available for following stale-

ness. They will give accurate means of comparing various factors of baking, ingredients, etc., as to their ability to prevent the change in the starch. However, more time and effort are necessary in order to develop physical tests, the results of which will be in better agreement with the thoughts of the consumers—human beings. It might be pointed out that as yet some of the existing methods have not been tested thoroughly enough; more work is needed on them to attempt to correlate the results with the thoughts of people.

The tests made by Cathcart and Luber on the freezing of bread to retard staling showed that, according to the tests based on the swelling of the starch in water, the bread was stale long before the human judges found it so.

Digestibility of Fresh and Stale Bread

Is fresh bread more digestible than stale bread? This question is often brought to our attention and many who have not actually asked the question have probably pondered over it.

Long ago Jungmann (1895) was able to find little difference, if any, between the action on fresh and on stale bread by the saliva of the mouth and by a ferment similar in part to that found in the stomach (pepsin-hydrochloric acid). Jungmann pointed out, although he was unable to prove it, that fresh bread might cause sensations of distress due to the fact that it forms lumps, since it requires little chewing for swallowing.

In 1904 Roux (1904) took up the study and concluded that stale bread is no more nor no less digestible than fresh bread.

Katz (1928) found that dogs secreted practically the same quantity of saliva, gastric juice, or pancreatic juice when fed fresh and stale bread. He also found that the enzyme diastase more readily attacked the starch of fresh bread than that of stale bread. These facts would indicate that fresh bread is the more digestible. However, Katz was able to show that, after salivation and chewing, stale bread was crumbly, while fresh bread formed heavy lumps. Those heavy lumps, of course, are more difficult to digest, as pointed out by Hammond (1857). Thus fresh bread which has been thoroughly masticated would be just as easily digested, if not better, than stale bread.

Alsberg (1936) suggests that in former times fresh bread was "promoted" as less digestible than stale bread, for relatively stale bread was served to keep down consumption. The serving of stale bread to reduce consumption is practiced by countries threatened with a wheat shortage even today. Alsberg concludes: "Under the conditions of the present, there seem to be no scientific data on record demonstrating any material difference in the food value or wholesomeness of fresh

and of stale bread." Thus stale bread is as nutritious as fresh bread (and *vice versa*) when protected from mold and contact infection.

Summary and Conclusions

This review explains to the best of our present knowledge what happens when bread stales, discusses methods of measuring staleness, and summarizes methods of preventing staleness. The inadequacy of our present knowledge of what happens when bread stales; the disagreement between physical or mechanical methods and the results of human judges as to the rate of bread staling; the lack of much scientific research on the effect of certain processes, ingredients, etc., in preventing bread staling; and the disagreement of existing data make definite conclusions difficult and point to the need for further strictly controlled scientific researches.

Some processes, ingredients, etc. have an effect on delaying staleness, while others have little effect, if any at all, and in some cases even decrease bread quality.

Many methods recommended for delaying crust staling increase crumb staling and *vice versa*. The two most effective methods for delaying crumb staling are heat and cold, yet these are not entirely practical at the present time. Considering the data presented for retarding the staling of crust and crumb it seems probable that a palatable loaf of good keeping qualities can be produced by:

1. Using flour with high-quality gluten,
2. Using liberal amounts of milk, shortening, and sugar (preferably sirup),
3. Using normal amounts of salt and yeast,
4. Using some malt extract and some moisture-retaining agent such as gelatinized starch,
5. Making a medium-slack dough by high-speed mixing,
6. Proper fermentation, handling, and baking,
7. Rapid cooling and wrapping after adequate cooling.

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DETERMINATION OF AMINO NITROGEN IN MALT EXTRACTS

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The need of a reliable method for the determination of amino nitrogen in malt extracts has been recognized by malt and brewing chemists for some time. Many methods have been proposed yet none is entirely free of inaccuracies.

The methods outlined in Cereal Laboratory Methods of the American Association of Cereal Chemists (1935) and Methods of Analysis of the Association of Official Agricultural Chemists (1935) are not sufficiently precise to justify their application to the determination of

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amino nitrogen in malt without considerable modification. Methods now in use in the various malt and brewing laboratories are: (*a*) Van Slyke's gasometric procedure (1911, 1912, 1913, 1929); (*b*) Foreman's alcoholic titration (1920); (*c*) Kolbach's modification (1928) of Sörensen's formol titration (1907, 1908), according to Pawlowski (1932); (*d*) Walters' modification (1937) of Folin's colorimetric method (1922); and some few electrometric titration methods of which the detailed procedure is unknown.

Considerations of primary importance in the selection of a method for routine purposes are simplicity, rapidity, accuracy, and consistency.

According to Richardson (1934), the Van Slyke method (*a*) is imperfect as it does not accurately estimate glycine, cystine, tryptophane, arginine, lysine and glutamine.

Foreman's alcoholic or acetone titrations (*b*) are inapplicable to malt extracts, as magnesium salts and various weak acids are titrated as amino nitrogen (Richardson, 1934).

Walters' colorimetric method (*d*) requires too much time and precision to be of any practical use. Employing the colorimetric, Van Slyke and Sörensen methods, Walters obtained results colorimetically that compared favorably with those by the Van Slyke method, though considerably lower than those by the Söresen titration.

The formol titration of Kolbach, outlined by Pawlowski (*c*), appears to be the most acceptable method, notwithstanding the adverse criticism of contemporary investigators. In defense of this statement it is necessary to consider the controversial aspects of the method.

Schryver and Thomas (1929) object to the lack of a suitable indicator. Walters is in agreement in this respect, maintaining that the end point is masked and that he could not attain the degree of precision claimed by Kolbach. Walters also objects to the cumbersome method of procedure. There is some justification for the latter criticism and for that reason certain deviations from the standard procedure are later proposed by the author. Richardson prefers the Van Slyke method for colored biological extracts even though uncertain results obtain. No alternate procedure is suggested by Richardson for the application of the formol titration for colored extracts that have not been treated with decolorants. By his admission, a titration at 50% neutralization covering a range of 4 pH units permits 97% titration, and a more complete estimation of amino acids with weak NH_2 groups. The author has experienced very little difficulty in measuring the color of the test solution, except in the instance of extremely dark-colored (caramel malt) extracts. It seems preferable, therefore, to follow the regular procedure in the formol method, rather than use a decolorant

that would remove 15% to 25% amino nitrogen. The color of normal extracts of malt does not interfere with the measurement of color to any serious extent, if properly compensated.

Some of the precautions outlined by Pawlowski were found to be superfluous, *viz*: adjustment of the formaldehyde, preparation of buffer solutions, and addition of barium chloride crystals, if specific substitute recommendations are superimposed.

The neutralization of formaldehyde is an unnecessary step, as commercial c.p. neutral formaldehyde (36% to 38%) can be easily obtained. Inferior grades of formaldehyde which are somewhat acidic, however, can be permanently neutralized by the addition of basic magnesium carbonate (Dunn and Loshakoff, 1936). Adjustment of the formaldehyde to pH 9.0 by means of sodium hydroxide is objectionable as a sediment is deposited on standing. A blank determination for the formaldehyde in the presence of the reagents used in the test compensates for the sodium hydroxide used to titrate the formaldehyde in the test. This is in disagreement with Pawlowski, who determines the blank on a water solution of formaldehyde.

TABLE I

VALUE OF THE "BLANK" DETERMINATION IN THE FORMOL TITRATION

	0.1N NaOH, *cc.*					
	Formaldehyde and distilled H_2O, pH 5.7		Formaldehyde and distilled CO_2-free H_2O, pH 7.0		Formaldehyde and reagents	
	North daylight	Daylight lamp	North daylight	Daylight lamp	North daylight	Daylight lamp
Thymol blue standard	1.0	1.0	1.0	1.0	0.7	0.7
Thymol blue and buffer, pH 9.0	1.0	1.0	1.0	1.0	0.7	0.7
Phenolphthalein and buffer, pH 9.0	1.5	1.5	1.5	1.5	1.3	1.3

Choice of Indicators

Neutral red and phenolphthalein, the most commonly used indicators for the formol titration, require a color standard composed of a buffer solution with the indicator for comparison in measuring the initial and final pH of the test solution. Equally suitable indicators for which commercially prepared pH color standards are available are preferable to laboratory-prepared standards. Much time can be saved if the preparation of buffer solutions is eliminated.

Substitute indicators that may be considered are thymol blue for phenolphthalein and bromthymol blue or phenol red for neutral red. It is simply a question of the suitability of the substitute indicator.

Thymol blue of pH 8.0 to 9.6 has a sensitive range, *i.e.*, pronounced color change, of pH 8.4 to pH 9.2, with an optimum change at pH 8.8 (Britton, 1929). The end point (pH 9.0) is easily distinguished and the course of the titration is easy to follow. Likewise, bromthymol blue, pH 6.0 to pH 7.6, has a sensitive range of pH 6.4 to 7.2, optimum change at pH 7.1. Experiments involving the use of all the indicators mentioned disclosed that thymol blue is just as suitable as phenolphthalein, and that bromthymol blue is even preferable to neutral red. Results obtained in the presence of phenolphthalein in conjunction with the buffered color standard were the same as those obtained with thymol blue in conjunction with the buffer color standard as well as the pH (commercial) color standard (Table II). More consistent results were obtained with bromthymol blue than with neutral red; however, neutral red was at its pKa at pH 6.8 and the end point was not so sharp. Phenol red, pH 6.8–8.4, may also be used in place of neutral red in fixing the initial pH of the test solution. Actually, with a little practice, the acid titration to pH 6.8 in the presence of phenol red may be accomplished without comparing the test solution with a color standard. The end point is reached at the complete permanent disappearance of the last trace of pink tint from the test solution.

TABLE II

VALUES OF AMINO ACIDS OBTAINED IN THE FORMOL TITRATION IN THE PRESENCE OF THYMOL BLUE AND PHENOLPHTHALEIN

Amino acid (pure solution)	Indicator used	Titrations, cc. of 0.1N NaOH			Mg. amino N	
		Total	Blank	Formol	Found	Present
Alanine	Thymol blue	6.0	1.0	5.0	7.0	7.0
Alanine	Phenolphthalein	6.5	1.5	5.0	7.0	7.0
Glycine	Thymol blue	6.0	1.0	5.0	7.0	7.0
Glycine	Phenolphthalein	6.5	1.5	5.0	7.0	7.0
IN THE PRESENCE OF ALL REAGENTS						
Alanine	Thymol blue	3.7	0.7	3.0	4.2	4.2
Alanine	Phenolphthalein	4.3	1.3	3.0	4.2	4.2
Glycine	Thymol blue	3.7	0.7	3.0	4.2	4.2
Glycine	Phenolphthalein	4.3	1.3	3.0	4.2	4.2

Other Observations

The final concentration of formaldehyde by this method (9%) is the optimum for maximum accuracy (Levy, 1934).

Barium chloride need not be added in crystalline form, as the addition of a solution containing an equivalent amount of barium chloride gave the same results.

Carbon dioxide did not seriously affect the results unless the solution was unduly exposed, or delivery pipettes were blown through.

Method

The procedure is modified as follows:

Pipette 60 cc. of extract or wort (12.5%) into a 100-cc. volumetric flask and immerse in boiling water for 10 minutes. Remove the flask, cool to room temperature, and treat with 10 cc. of 20% solution of barium chloride and 5 cc. of a saturated solution of barium hydroxide (7 cc. of barium hydroxide solution is necessary to provide an excess for proteolytic extracts), make up to 100 cc. with distilled water, shake and let stand for 30 minutes. Filter through No. 588 Schleicher and Schüll fluted filter paper or its equivalent (18.5 cm.), covering the funnel with a large watch glass.

Pipette four 20-cc. aliquots into four 125-cc. Erlenmeyer flasks (numbered 1, 2, 3, and 4), and plug with rubber stoppers. Prepare a blank solution in the same manner, substituting distilled water for the extract or wort.

To flask No. 1 add 2 cc. of 0.02% phenol red. To flask No. 2 add 2 cc. of distilled water. To Nos. 3 and 4 add 2 cc. each of 0.04% thymol blue.

Titrate flask No. 1 solution with 0.1 N hydrochloric acid to a distinct yellow (pH 6.8, the color should not immediately "fade" back). Add the same amount of hydrochloric acid required for flask No. 1 to each of flasks 2, 3, and 4. Add 10 cc. of 36% to 38% reagent-grade, neutral formaldehyde, pH 5.6 (formaldehyde of lower pH must be adjusted) to each of flasks 2, 3, and 4. Reject flask No. 1. Titrate the solution in No. 3 with 0.1 N sodium hydroxide to a near match with thymol blue pH 9.0 color standard (avoid overtitration—a little practice will aid in the judgment of approximate amount—or this titration may serve as an incremental titration in preparation for the titration of No. 4 solution). Add an equal amount of sodium hydroxide to flask No. 2. Compare solution 3 plus water ampoule with thymol blue color standard plus solution No. 2 in a color comparator, using daylight lamp or north light. A roulette comparator with a daylight lamp is most convenient for this purpose. If the test solution almost matches the standard, bring the solutions in flasks 2 and 3 to a total of 40 cc. each with distilled water and complete the titration to an exact match. A difference of 1 cc. in total volume in the test solution and solution No. 2 does not seriously affect the result. A more accu-

rate estimation is possible in the titration of solution No. 4. An analysis of the same solution on different days when the daylight varies in intensity will cause the results to vary. It is almost imperative that a standard daylight lamp be used for accuracy. The use of color standards of pH 9.0 on both sides of the test solution in the comparator permits a very close matching of colors. The addition of one drop of 0.1 N NaOH to a "matched" test solution should produce a color that, to the eye, is apparently darker than the standard.

The blank is determined in the same manner, except that ampoules of water are used in conjunction with the thymol blue standards instead of the compensating wort solution (flask 2).

The amino nitrogen is calculated as:

$$\% \text{ amino } N_2 = \frac{(T - B) \times 14 \times N}{M} \times 100,$$

where:

T = cc. of NaOH (test solution titer)
B = cc. of NaOH (blank solution titer)
N = normality of NaOH
14 = mg. of nitrogen per cc. N NaOH
M = mg. of dry matter (moisture excepted) represented in each aliquot.

Titrating with 0.107N ± NaOH (0.106N to 0.108N) for 12.5% extracts, the equation becomes:

$$\% \text{ amino } N_2 = \frac{(T - B) \times 14 \times 0.107}{1500} \times 100 = (T - B) \times 0.1.$$

To convert to dry basis divide by (100% − % moisture of the malt).

Consistency of the Method

Walters (1937) obtained results by Kolbach's method varying from 0.1 cc. to 0.25 cc. of 0.1N sodium hydroxide, for duplicate estimations. It is assumed that the determinations were for duplicate aliquots of a given wort rather than determinations for duplicate extracts of a given malt.

The consistency of the method is best illustrated in Table III. A bulk sample of barley was thoroughly mixed and divided into two parts. Each part was subdivided into six equal parts. Two maltings were made under the same optimum conditions. Each sample of kilned malt was divided into two parts (*a* and *b*) and separate extractions (worts) made. Each wort was analyzed in duplicate. The variance of the nitrogen in the wort is given as well as the amino nitrogen to show

TABLE III

VARIABILITY OF RESULTS OF WORT NITROGEN AND AMINO NITROGEN

Sample number[1]		Wort nitrogen				Amino nitrogen in wort				Amino N/wort N ratio
		% Total D.M. wort	Mg. in 100 cc. wort	Mg. deviation from avg.	% Mg. N deviation	% Total D.M. amino	Mg. in 100 cc. wort	Mg. deviation from avg.	% Mg. N deviation	
1	1*a*	.560	70.0	−0.3	−0.42	.185	23.6	+0.2	+0.85	33.03
	1*b*	.559	69.9	−0.4	−0.57	.175	22.3	−1.1	−4.70	31.30
2	2*a*	.566	70.8	+0.5	+0.71	.190	24.2	+0.8	+3.41	33.60
	2*b*	.562	70.3	0.0	0.00	.190	24.2	+0.8	+3.41	33.80
3	3*a*	.568	71.0	+0.7	+1.00	.180	23.0	−0.4	−1.71	31.70
	3*b*	.567	70.9	+0.6	+0.85	.185	23.0	−0.4	−1.71	31.74
4	4*a*	.570	71.3	+1.0	+1.42	.185	23.6	+0.2	+0.85	32.45
	4*b*	.560	70.0	−0.3	−0.42	.185	23.6	+0.2	+0.85	33.03
5	5*a*	.564	70.5	+0.2	+0.28	.185	23.6	+0.2	+0.85	32.80
	5*b*	.556	69.5	−0.8	−1.14	.185	23.6	+0.2	+0.85	33.27
6	6*a*	.556	69.4	−0.9	−1.28	.180	23.0	−0.4	−1.71	32.43
	6*b*	.563	70.4	+0.1	+0.14	.185	23.6	+0.2	+0.85	32.85
Average		.563	70.3	—	—	.184	23.4	—	—	32.66
range		.015	1.9	1.9	2.70	.015	1.9	1.9	8.11	2.5
7	7*a*	.569	71.1	+0.2	+0.28	.195	24.9	+0.2	+0.81	34.27
	7*b*	.564	70.5	−0.4	−0.56	.195	24.9	+0.2	+0.81	34.57
8	8*a*	.570	71.3	+0.4	+0.56	.195	24.9	+0.2	+0.81	34.21
	8*b*	.570	71.3	+0.4	+0.56	.195	24.9	+0.2	+0.81	34.21
9	9*a*	.564	70.5	−0.4	−0.56	.195	24.9	+0.2	+0.81	34.57
	9*b*	.568	71.0	+0.1	+0.14	.195	24.9	+0.2	+0.81	34.33
10	10*a*	.565	70.6	−0.3	−0.42	.195	24.9	+0.2	+0.81	34.51
	10*b*	.579	72.4	+1.5	+2.10	.201	25.6	+0.9	+3.64	34.71
11	11*a*	.565	70.6	−0.3	−0.42	.195	24.9	+0.2	+0.81	34.51
	11*b*	.561	70.1	−0.8	−1.12	.190	24.2	−0.5	−2.02	33.84
12	12*a*	.559	69.9	−1.0	−1.40	.185	23.6	−1.1	−4.45	33.09
	12*b*	.569	71.1	+0.2	+0.28	.185	23.6	−1.1	−4.45	32.51
Average		.567	70.9	—	—	.193	24.7	—	—	34.11
range		.020	2.5	2.5	3.50	.016	2.0	2.0	8.09	2.2
Grand average		.565	70.6	—	—	.189	24.1	—	—	33.4
Grand range[2]		.024	3.0	3.0	4.30	.026[3]	3.3	3.3	13.60	3.4

[1] Each value given is the average of duplicate determinations. Extractions *a* and *b* are duplicate. Samples 1 to 6 and samples 7 to 12 are replicates. Samples 1 to 6 and 7 to 12 are duplicate maltings.
[2] Represents 0.6 cc. of 0.1N NaOH (wort N).
[3] Represents 0.26 cc. of 0.107N NaOH (amino N) (over all titration range).

the variability within the sample, in malting, and within the wort, as determined by analysis of the nitrogen in the wort.

An example of variance between extracts is best illustrated by sample 10*b* (Table III). Although the mg. deviation from the mean deviation for amino nitrogen is considerable, the mg. deviation from the mean for the corresponding wort nitrogen is equally noticeable.

The values given in Table III are the averages of duplicate determinations. Of 24 duplicate determinations made, 22 checked exactly, and 2 within 0.6375 mg. of nitrogen in terms of 100 cc. of wort. Eight duplicate worts checked exactly and 4 checked within 0.6, 0.7, 1.3, and 1.4 mg., respectively, per 100 cc. of wort. Apparently, variation in values obtained may be attributed considerably to variable malting conditions and variability within the sample and within the extract.

Summary

Practically pure neutral formaldehyde is easily obtained and should be used in preference to cloudy formaldehyde that sediments on standing. Inferior grades are objectionable as they interfere with the continuity of procedure and the technique of the analyst.

The blank for the formaldehyde is useless unless determined in the presence of the reagents used in the test.

The use of a standard commercial set of pH color standards is more convenient than the use of buffer solutions used in conjunction with indicators. The pH of the buffer solutions is subject to change from day to day due to handling and exposure to carbon dioxide in the atmosphere. The preparation of the buffer solutions is time consuming and tedious.

The use of phenol red and thymol blue indicators is preferable to neutral red and phenolphthalein indicators, respectively. The amount of indicator in the test solution must be equal to the amount in the color standard.

Greater accuracy is possible by use of a daylight lamp and comparator combination, than by daylight.

The modified method, simplifying Pawlowski's method, is convenient, consistent, and adaptable to routine purposes.

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REPORT OF THE 1938–39 COMMITTEE ON METHODS OF ANALYSIS

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(Read at the Annual Meeting, May 1939)

The members of the Methods Committee during the past year have conducted the following investigations of methods: the gas retention of doughs, the evaluation of yeasts for baking purposes, a collaborative study of the 15-minute moisture method, and a study of methods of determining proteolytic activity. The study of methods of titration of mono-calcium phosphate was postponed because of the introduction of a new type of mono-calcium phosphate which might necessitate some adjustments in the methods.

Recommendations

1. That the study of methods for evaluating yeasts be continued.
2. That a study be made of methods for the titration of mono-calcium phosphate.

3. That the investigation of gas retention be continued.
4. That a collaborative study be made of the Binnington-Geddes rapid method for determining wheat and flour pigments.
5. That the collaborative study of the 15-minute moisture method be completed.
6. That a collaborative study be made of experimental milling.
7. That the study of methods of determining proteolytic activity be continued.

BOOK REVIEW

Getreidelagerung, unter besonderer Berücksichtigung der bauerlichen und landwirtschaftlichen Verhältnisse. By Kurt Seidel, B. Czyźewsky, and W. Hammer. Second edition. Schriften des Reichskuratorium für Technik in der Landwirtschaft, Heft 58. Beuth-Vertrieb GmbH, Berlin, 1938. 150 pages, illustrated. Price RM 4 (paper covers).

This little manual is designed primarily to instruct the farmer in the best methods of handling newly harvested grain in the field and in the granary. Aside from this, however, it presents much valuable scientific information on the storage of grain in large quantities, and includes chapters on artificial drying of grain and storage of flour and feed.

A good share of the information in this book has to do with the precautions necessary to prevent respiration losses and damage in moist grain. Because the harvest season in Germany is frequently accompanied by rains and high humidities, the average moisture content of the grain when harvested rarely runs below 15%–16% in normal years, while in wet years it mounts to 18% or higher. Only in very dry years does the moisture content fall below 15%. Some years ago Hoffman estimated that the losses due to unfavorable harvest weather amounted to 60 million marks in dry years and 250 million marks in wet years. Other authors have estmiated that in wet years the losses may run as high as 10% of the total crop. Aside from these losses, the value of the grain is impaired by sprout damage, and the high moisture content necessitates either artificial drying or frequent moving during storage.

The book opens with a brief chapter by K. Seidel, outlining in non-technical language "what every farmer must know" about the storage of his grain, and indicating the precautions necessary to prevent excessive respiration losses and insect damage.

This simple outline is elaborated upon in the next section, by B. Czyźewsky, which comprises the bulk of the book. This is an able scientific discussion of many of the factors involved in the storage of grain on the farm and in large commercial granaries and elevators. Respiration, sweating, adsorption of moisture and odors, and infection with microörganisms are touched upon. Precautions to be observed during storage of unthreshed grain in stacks and in sheds are mentioned.

In connection with the discussion of sprout damage, attention is called to the work being done at the Leipzig Institut für Pflanzenbau, in selecting grain varieties which sprout less readily at the high moisture levels common in German grain, especially wheat and rye. It is anticipated that the widespread cultivation of these varieties will considerably reduce losses due to sprout damage.

Methods of combating insect pests of stored grain are set forth at some length, and information is given on the use and efficacy of a wide variety of insecticides.

Various methods of effecting natural or forced ventilation of granary floors are described and illustrated, as are also ventilating systems for large and small grain elevators. A useful grain aeration table is included, from which can be determined the maximum relative humidity permissible in the air admitted for aeration, in order that it shall not carry more than 75% relative humidity when it has attained the temperature of the grain.

The storage of flour and bran is the subject of a short chapter by K. Seidel. It points out that in order to prevent further increase in moisture content and possible spoiling, aeration of warehouses containing moist flour should not be undertaken unless the relative humidity of the outside air is less than 75% and its temperature not more than 3°C. lower than that of the flour. Effects of damage by fresh and salt water on sacked flour are discussed.

The principles of artificial drying of grain are outlined by W. Hammer, and 10 types of German grain dryers are described.

A supplement presents 70 questions and answers dealing with storage of grain and cereal products. This serves as a summary of the foregoing chapters, and includes information not previously given, especially with regard to the milling quality of damaged grain.

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